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ANALYSIS AND INTERPRETATION OF ASSINIBOINE RIVER SEDIMENT STATION DATA

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Canada

Western and Northern Region

90-06748/

ANALYSIS AND INTERPRETATION OF ASSINIBOINE RIVER SEDIMENT STATION DATA

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Report submitted to Environment Canada, Water Resources Branch, Winnipeg, March 1990.

ABSTRACT

Water Resources Branch, Environment Canada has operated six sediment stations on the Assiniboine River. These are, in downstream order, Kamsack, Russell, Holland, Rossendale, Portage la Prairie and Headingley. Programs were initially begun in 1956 by PFRA and taken over by WRB in the early 1960s. The longest running station is at Headingley, near the confluence with the Red River. Most of the rest of the stations were established in the late 1960s to monitor the effects of the Lake of the Prairies and Portage Diversion on sediment regimes in the river. Generally these stations ran for 6 to 10 years in the 1970s. The stations near Holland and at Headingley are the only ones currently active.

Review of the sediment data for each station shows that in all cases, except Rossendale, the period of sediment data cover the range of discharges successfully. The flow and sediment regimes at all the stations are affected by flow regulation to some extent. This is especially true near Russell, Portage la Prairie and Headingley where flow regulation has reduced spring flood discharges to a fraction of their natural magnitude and enhanced low flows in fall and winter. At the same time the peak sediment concentrations have also been reduced at Portage and Headingley. In several cases the peak concentration and discharge no longer coincide.

Average sediment concentration and load increase downstream along the river. This is particularly noticeable between Russell and Holland. Downstream of Holland the changes are relatively small, even prior to opening of the Portage Diversion. Similarly, mean annual loads increase dramatically between Russell and Holland (from 20 000 Mg to 500 000 Mg) before levelling off in the downstream part of the basin. The Portage Diversion removes, on average, 27% of the mean annual load of the river (measured near Holland), compared with 16% of the mean annual discharge. Combined with sedimentation in Portage Reservoir, this explains the decrease in average concentration at Portage and Headingley. Currently, standard errors of the estimate of the mean annual load are typically 20-30% and require considerably longer periods of record to reduce them substantially.

Mean annual sediment yields are difficult to assess accurately but the general pattern is that the upper basin has very low yields (< 3 Mg km^{-2} yr^{-1}), the central part of the basin relatively high yields (16 Mg km^{-2} yr^{-1}) and the lower basin (prior to the Portage Diversion) relatively low yields. In fact, if the load at Holland is subtracted, the lower basin has negligible sediment yield.

Soil erosion risk maps suggest that the contribution of fluvial sediment from much of the basin is probably minor. Similarly, the contribution of suspended sediment load from tributary streams is low, or appears likely to be low from their discharge and geomorphic character. On the other hand, there is great potential for sediment supply from riparian sources where the Assiniboine is incised into the silty sand of the Assiniboine Delta, between Brandon and Portage la Prairie. This is probably the major source of sediment to the present river.

The present sediment data network provides an excellent record of the sediment regime of the Assiniboine River. Some additional useful information on sediment sources could be obtained from network adjustments, particularly a sediment station at Brandon and miscellaneous stations on some of the larger tributaries. There is no compelling reason to maintain operation of the currently active stations at Headingley and near Holland, although if a station were added at Brandon it would be useful to maintain operation of the Holland station for comparison.

RÉSUMÉ

La Direction des ressources en eau (DRE) d'Environnement Canada a exploité six stations d'étude des sédiments sur la rivière Assiniboine. Il s'agit, en descendant vers l'aval, des stations situées à Kamsack, à Russell, à Holland, à Rossendale, à Portage La Prairie et à Headingley. L'ARAP a entrepris les programmes d'étude en 1956, et la DRE a pris la relève au début des années 60. La station qui compte le plus grand nombre d'années d'exploitation est celle située à Headingley, près de sa confluence avec la rivière Rouge. Les autres stations ont été établies pour la plupart à la fin des années 60 en vue de surveiller les effets de la dérivation Portage à la hauteur du Lake of the Prairies sur les régimes des sédiments dans la rivière. Ces stations ont en général été exploitées de 6 à 10 ans dans les années 70. Les seules encore en service sont celles établies aux environs de Holland et à Headingley.

En examinant les données sur les sédiments de chacune des stations, on remarque dans tous les cas, à l'exception de Rossendale, que le période de collecte des données englobe bien tout l'eventail des débits. Les régimes de l'écoulement et des sédiments à toutes les stations sont touchés dans une certaine mesure par la régularisation de l'écoulement. Ce phénomène est particulièrement évident près de Russell, de Portage La Prairie et de Headingley où la régularisation a réduit à une fraction de leur importance naturelle les crues printanières et augmenté les faibles débits en automne et en hiver. Simultanément, les concentrations maximales des sédiments ont diminué à Portage et à Headingley, et, dans plusieurs cas, les concentrations et les débits maximaux ne coincident plus.

La concentration et le transport moyens des sédiments augmentent en aval le long de la rivière, notamment entre Russell et Holland. En aval de Holland, les changements sont relativement mineurs, même avant l'ouverture de la dérivation Portage. De même, le transport annuel moyen augmente considérablement entre Russell et Holland (de 20 000 à 500 000 Mg) avant de se stabiliser dans la portion aval du bassin. La dérivation Portage réduit de 27%, en moyenne, le transport annuel moyen de la rivière (mesuré près de Holland), comparativement à 16% du débit annuel moyen. En ajoutant à cela la sédimentation enregistrée dans le résevoir Portage, voilà qui explique la baisse de la concentration moyenne à Portage et à Headingley. À l'heure actuelle, l'écart type de l'estimation du transport annuel moyen se situe entre 20 et 30% pour la plupart des stations, et il faut songer à baser ce calcul sur des périodes de relevés bien plus longues pour réussir à réduire cet écart de façon notable.

La production annuelle moyenne de matières est difficile à évaluer avec précision; toutefois, la tendance qui se dessine est la suivante : très faible production dans le bassin supérieur (< 3 Mg $km^{-2}.an^{-1}$); production relativement élevée dans la partie centrale (16 Mg $km^{-2}.an^{-1}$); production assez faible dans le bassin inférieur (avant la dérivation Portage).

En fait, si l'on soustrait le transport enregistré à Holland, la production est alors négligeable dans le bassin inférieur.

Les cartes des risques d'érosion des sols semblent indiquer que l'apport des sédiments fluviaux provenant de la majorité du bassin est probablement mineure. De même, la contribution des sédiments en suspension provenant des affluents est faible ou semble l'être si l'on se fie à leur débit et à leurs caractéristiques morphologiques. Par ailleurs, il y a de fortes chances pour que les sédiments proviennent des berges de sable limoneux où l'Assiniboine rejoint le delta du même nom, entre Brandon et Portage la Prairie. Cet endroit constitue probablement la principale source de sédiments.

Le réseau actuel de stations d'étude des sédiments fournit d'excellentes archives sur le régime des sédiments de la rivière. On pourrait obtenir quelques autres renseignements utiles sur la provenance des sédiments en apportant certaines modifications au réseau, notamment à la station située à Brandon et à des stations où les prélèvements sont occasionnels sur certains des plus gros affluents. Rien ne justifie la poursuite de l'exploitation des stations présentement actives à Headingley et près de Holland; toutefois, si on ajoutait une station à Brandon, il serait bon de maintenir celle de Holland pour pouvoir établir des comparaisons.

ACKNOWLEDGEMENTS

I am grateful to Larry Heinze (WRB Regina), John Everitt (Brandon University), Bill Rannie (University of Winnipeg) and Frank Penner (Manitoba Ministry of Natural Resources, Water Resources Branch) for background information on the Assiniboine. Dick Coote (Land Resources Research Institute, Agriculture Canada) helped me understand and interpret the soil erosion risk maps. Ted Yuzyk (Sediment Survey Section, WRB, Ottawa) provided useful advice throughout. The report has benefitted from reviews by Ted Yuzyk and Frank Penner. Thanks also to Mike Kowalchuk (A/Chief, WRB Winnipeg) who was Scientific Authority for the contract and was a great help in seeing it to completion, and to Joan Ellsworth for drafting.

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1. INTRODUCTION AND OBJECTIVES

The Prairie Farm Rehabilitation Administration (PFRA) began collecting suspended sediment data in the Assiniboine River in 1956 to provide background information for water resources projects. More complete data collection programs began in 1962 when the national sediment program was initiated by Water Resources Branch, Inland Waters Directorate. To date, sediment sampling has involved 6 stations along the main stem of the Assiniboine River. These include a station at Headingley, near the confluence with the Red River, which has a sediment record extending from 1956 to the present, making it one of the longest records on any Canadian river. The objective of this report is to summarize and analyse the existing sediment data and to evaluate the WRB sediment program on the river. In addition, the report is part of a larger project to assess the possibility of merging data bases from several agencies for description and assessment of the hydrology, sediment, water quality and other environmental attributes of the stream system. Specifically the objectives of the report are to:

1. Assess the existing sediment data base for the six WRB stations on the Assiniboine River and sediment data from Water Quality Branch. This includes consideration of the representativity and range of conditions covered by the data, annual and seasonal loads and concentrations, time

distribution of concentration and load, and changes in regime caused by flow regulation, diversion and reservoirs.

2. Investigate the sediment yield and routing of suspended sediment through the stream system, including identification of major sediment sources within the basin from the WRB data.

3. Evaluate other data bases for information of use in interpreting the suspended sediment regime of the Assiniboine River, particularly hydrology, land use, soils, surficial geology and geomorphology.

4. Evaluate the existing WRB sediment monitoring activities in the river basin and recommend changes to the activities that would improve understanding of the suspended sediment regime of the stream system and allow other data bases to be routinely used in sediment data analysis.

2. ASSINIBOINE RIVER BASIN: HYDROLOGY AND GEOMORPHOLOGY

The Assiniboine River system upstream of Headingley drains approximately 153 000 km^2 of south eastern Saskatchewan and south western Manitoba (Fig. 1). Of this total area, the two major tributaries, the Qu'Appelle River and the Souris River, account for approximately 50 000 km^2 and 60 000 km^2 each (Table 1). Large areas of the basin are internally drained and do not contribute runoff to the stream system in 'normal' years (Prairie Farm Rehabilitation Administration, 1989). This reduces the "effective" drainage area to about 40% of the gross area, i.e. approximately 60 000 km^2 at Headingley, of which the Qu'Appelle and Souris comprise 17 000 km^2 and 21 000 km^2 respectively (Table 1).

The Assiniboine River originates in the plains of east central Saskatchewan northwest of Preeceville and extends for 1290 km to its confluence with the Red River in south central Manitoba. Likewise, the Qu'Appelle and Souris Rivers rise in the plains of south-central Saskatchewan, and therefore the flow regime of the Assiniboine River is entirely dependent on prairie runoff, primarily during spring snowmelt.

Within the Assiniboine River basin there are pronounced spatial trends in the annual water balance, particularly between the headwater areas of the Souris and Qu'Appelle rivers and the Manitoba uplands (Riding Mountain and Duck Mountain). Mean annual precipitation shows a gradual eastward increase across the basin. In the

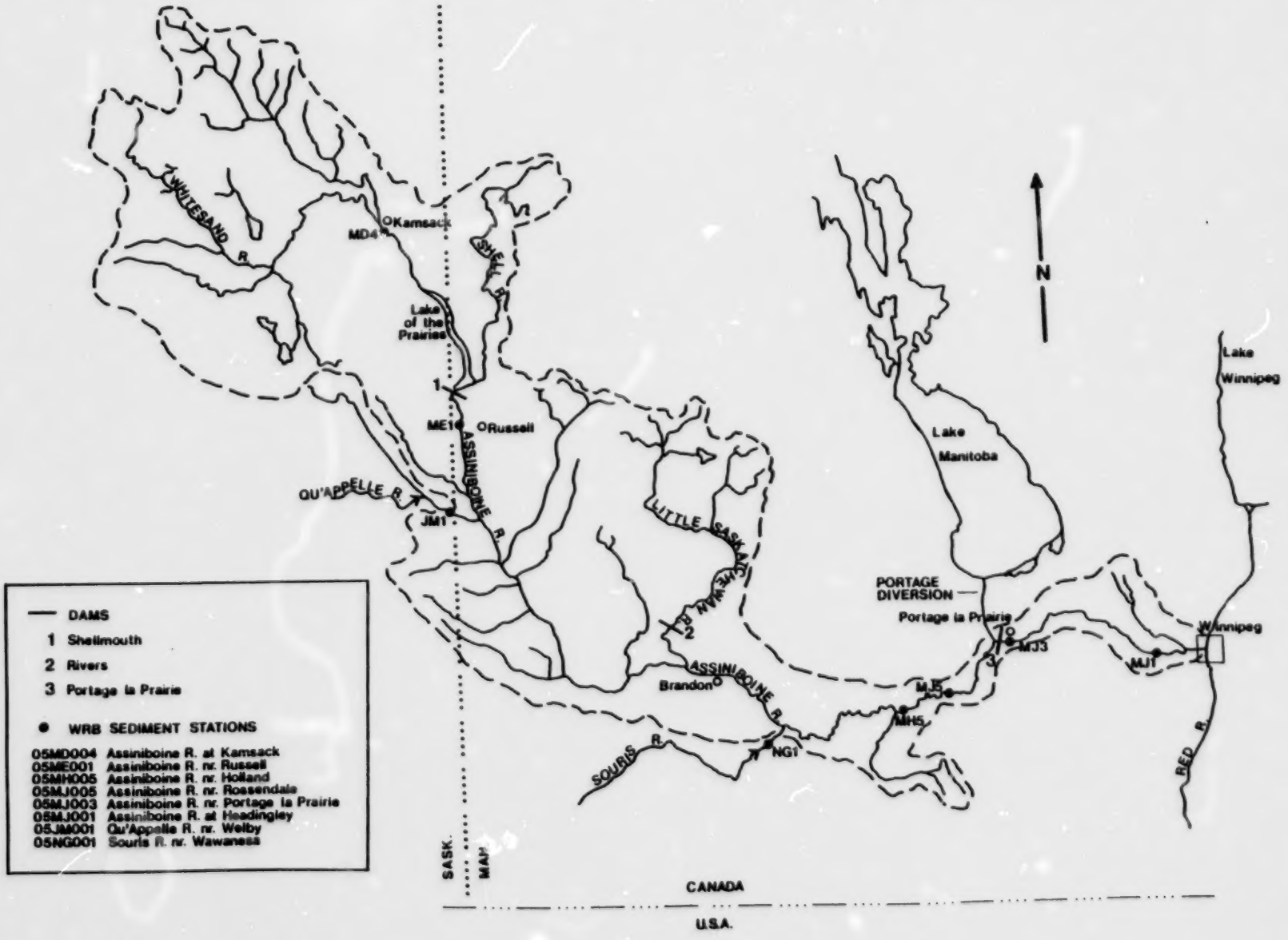

Figure 1 Assiniboine River Basin

TABLE 1 Drainage Areas for Sediment Stations in the Assiniboine River Basin

Station name	Station Number	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)
Assiniboine River at Kamsack	05MD004	12 950	4 324
Assiniboine River near Russell	05ME001	19 300	7 664
Assiniboine River near Holland	05MH005	151 700	58 140
Assiniboine River near Rossendale	05MJ005	151 900	58 300
Assiniboine River near Portage la Prairie	05MJ003	152 400	58 740
Assiniboine River at Headingley	05MJ001	153 400	59 770
Qu'Appelle River near Welby	05JM001	50 080	17 080
Souris River at Wawanesa	05NG001	61 130	21 490

western portions of the Qu'Appelle and Souris basins precipitation is less than 400mm, but in western Manitoba it is over 400mm, and increases to over 500mm in the easternmost portion of the basin and over the uplands of the Manitoba Escarpment north of the Assiniboine River (Environment Canada, 1984).

Furthermore, annual evapotranspiration is almost equal to the annual precipitation and therefore annual runoff is very low; less than 25mm [and as low as 3.5 mm,(Rannie et al., 1989)] in the Saskatchewan portion of the basin, increasing to 50 or 100 mm in the northern and eastern portions of the basin (Department of Fisheries and Oceans, Hydrological Atlas of Canada, 1978). The summer months always have a large water deficit. The net result is that, although the Souris and Qu'Appelle river basins account for almost 72% of the gross drainage area and 64% of the effective drainage area of the Assiniboine River, they contributed only 38% of the annual flow of the Assiniboine River at Holland between 1975 and 1984. Annual water yield per unit area for the Qu'Appelle and Souris basins is about half that for the Assiniboine basin. Downstream across the Assiniboine basin the average annual water yield remains approximately constant at 12 $dam^3\ km^{-2}$. The tributaries draining the Manitoba uplands are therefore crucial to maintaining and contributing flow to the Assiniboine River. The generally very low runoff amounts throughout the basin have a great influence on the average suspended sediment loads of the streams.

The upper part of the course of the Assiniboine River flows in a broad shallow valley through the Saskatchewan plains and the basin of glacial Lake Assiniboine, but in the vicinity of Kamsack it becomes confined in a large glacial spillway where it remains until reaching Brandon. The spillway varies in depth from 25 to 85 metres, and in bottom width from 400 to 800 metres. The present river is underfit and highly sinuous throughout its course in the spillway. The meander belt occupies the full width of the valley bottom but the channel has been artificially straightened in places. Overbank flooding is common along some portions of the valley, but elsewhere the river is incised up to 7 metres below the floodplain [e.g. for several kilometres upstream of the Qu'Appelle confluence (Klassen, 1975)]. The valley sides consist of dissected and slumped bedrock and Pleistocene deposits (Klassen, 1975).

From Brandon to Portage la Prairie the stream has incised a deep (70 - 80 metres), narrow (500 metres), sinuous valley through the Late Pleistocene Assiniboine Delta, which was formed at the point where the discharge of the spillway entered Lake Agassiz. Deltaic deposits are exposed in many places by stream erosion of the valley sides. This portion of the channel contains numerous sand bars and some extensive unvegetated point bars - the only section of the river to show such evidence of active sedimentation and channel migration. This portion of the valley also contains some extensive alluvial terrace remnants, apparently related to base-level adjustment during the later phases of Lake Agassiz (Klassen, 1975). Much of the present sediment load

of the Assiniboine is derived from this section of the valley between Brandon and Holland [Fig. 2(a)].

East of the Manitoba Escarpment the depth of incision declines gradually until at Portage la Prairie the river is barely below the surface of the Lake Agassiz plain. Downstream of Portage la Prairie the Assiniboine flows across the Lake Agassiz plain over which it has deposited a low gradient alluvial fan as a result of frequent avulsion throughout the Holocene (Rannie et al., 1989; Rannie, in press). The present river, confined by dikes and regulated by the Portage Diversion, is no longer subject to avulsion.

In the spillway upstream of Brandon the channel gradient averages 0.00013, increasing to 0.00036 between Brandon and Portage and then decreasing downstream to 0.0003, prior to steepening slightly near the confluence with the Red River [Figure 2(b) see also Klassen, 1975; Prairie Provinces Water Board, 1982; Wolowich and Tamburi, 1985 and Rannie, in press]. The sinuosity is generally between 1.5 and 2.0 along the entire length of the river, but in places exceeds 2.0.

Both the Qu'Appelle and Souris Rivers , together with smaller tributaries such as the Shell and Little Saskatchewan (Minnedosa) rivers, are tortuous and underfit within glacial spillways along much of their length. In the case of the Qu'Appelle

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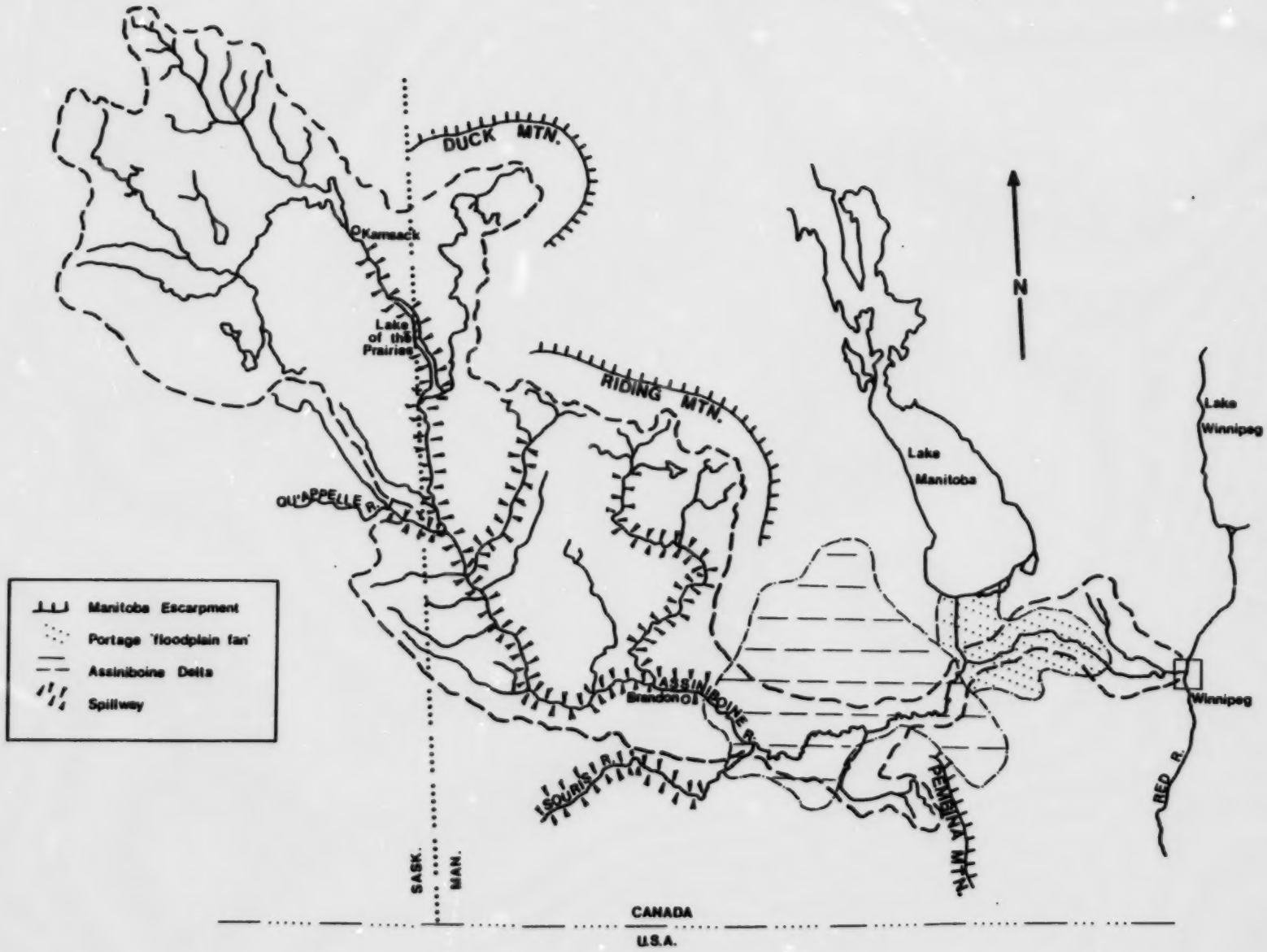


Figure 2a Geomorphology of the Assiniboine River Basin

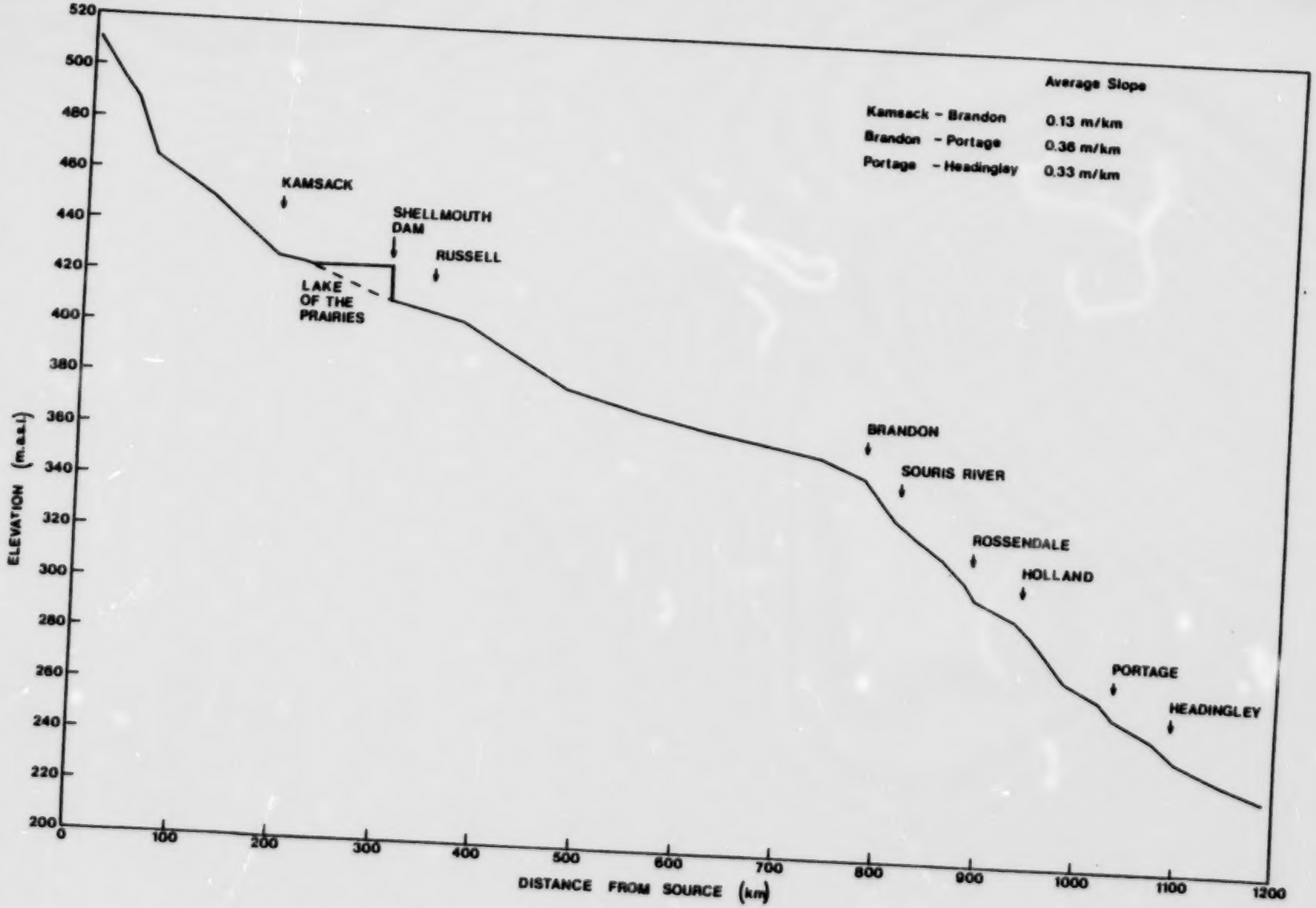


Figure 2b Longitudinal Profile of the Assiniboine River

River the valley floor is occupied by a string of lakes. The station descriptions later in the report contain further information on the channel and valley morphology in the vicinity of each of the sediment stations.

Apart from the deep, trough-shaped river valleys, much of the landscape of the drainage basin west of the Manitoba Escarpment consists of hummocky or corrugated moraine and gently sloping till plains (Klassen, 1975, 1979; Manitoba Department of Energy and Mines, 1981; Agriculture Canada, 1987). Local slopes are typically only a few degrees, although in some areas of greater relief (e.g. Riding Mountain) slopes reach 15 to 20 degrees. Occasionally Cretaceous bedrock (Riding Mountain Formation) with only thin, local veneers of glacial deposits occur, as well as areas of outwash and glaciolacustrine deposits (especially south and west of Brandon, in the basin of glacial Lake Souris). In the eastern portion of the basin the landscape is dominated by the level or gently sloping surface of the Lake Agassiz Plain, Assiniboine Delta and the Portage la Prairie 'floodplain fan'. The present surface of the Assiniboine Delta is covered by largely inactive sand dunes, particularly in the vicinity of Carberry and Spruce Woods Provincial Park. The underlying deposits are predominantly silty sand and clay of Quaternary glacio-fluvial or Holocene alluvial origin.

There are no natural lakes on the Assiniboine River main stem but several of the larger tributaries have lakes on them. More significantly for the present sediment regime of the river, there are several reservoirs on the main stem and its tributaries, constructed during the period of WRB sediment monitoring (Fig. 1). Two of these on the main stem, the Shellmouth Dam and the Portage Diversion, are particularly significant. The Lake of the Prairies (Shellmouth Dam), upstream of Russell on the Manitoba-Saskatchewan border, was completed in 1969 as part of the Flood control scheme for the City of Winnipeg. At full supply level the reservoir volume is 475 000 dam^3 but its use for flood control means that it is highest immediately after spring runoff and then gradually drawn down during the fall and winter to accommodate the next spring flood. The Portage Diversion and Reservoir, which began operation in 1970, also have a significant effect on the flow and sediment regime of the lower Assiniboine River. As in the case of the Lake of the Prairies, the Portage Reservoir is at its lowest level in late winter prior to spring runoff, and is then drawn down during the fall and winter.

Smaller reservoirs on tributaries include the Rivers Reservoir on the Little Saskatchewan River and the Whitesand Reservoir (Theodore Dam) on the Whitesand River in eastern Saskatchewan (Fig. 1). The flow of the Souris River has apparently been altered by several drainage projects and reservoirs. Their net effect has apparently been to augment winter and summer flows, reduce the spring peak and

reduce annual average flow near the Red-Assiniboine confluence to about 90% of natural (Prairie Provinces Water Board, 1982). The Qu'Appelle River flow has also been subject to substantial alteration including augmentation by diversion of water from Lake Diefenbaker, channel improvement, reservoirs and drainage schemes. The net result has been to alter the average flow by very little but to augment winter flows substantially in some years (Prairie Provinces Water Board, 1982).

In general, the effect of these flow regulation projects on the mainstream and the tributaries has been to augment winter flows, reduce the spring peak flows, and to slightly reduce total annual flows on the main stem - Prairie Provinces Water Board (1982) estimated that the 'present use' flow of the Assiniboine River at Headingley is about 88% of the calculated 'natural flow'. The effects on the sediment regime of the Lake of the Prairies (Shellmouth Dam) and the Portage Diversion in particular are discussed in detail later in the report.

3. SUSPENDED SEDIMENT DATA PROGRAMS

Suspended sediment data collection began in the Assiniboine River in 1956 at Headingley and Portage la Prairie, as part of reconnaissance studies of sediment loads in prairie streams, for water resources development (Fig. 3). The program was extended under the Water Resources Branch beginning in 1961. Continuous (year round) data collection began at Headingley in 1962, and at Portage la Prairie in 1963. At the time of construction of the Shellmouth Dam and Portage Diversion, the program was extended to assess loadings to each of these reservoirs. Thus, in 1969 and 1970 sediment stations were established at Rossendale, Holland, Russell and Kamsack. The Rossendale station operated for only three years and for practical purposes the stations at Rossendale and Holland can be treated as one. The Holland and Headingley stations remain active as important basin monitoring stations, but the remaining stations were closed in the mid and late 1970s. Figure 1 shows the location of each of these stations, while Figure 3 provides a summary of their operation, and Table 1 gives information about the drainage area upstream of each station.

Data collection at these six stations has included suspended sediment concentrations and load calculations, particle size analysis of depth integrating samples, dissolved solids concentrations, point integrating samples and bed material. The data collected at each station are summarized in Table 2.

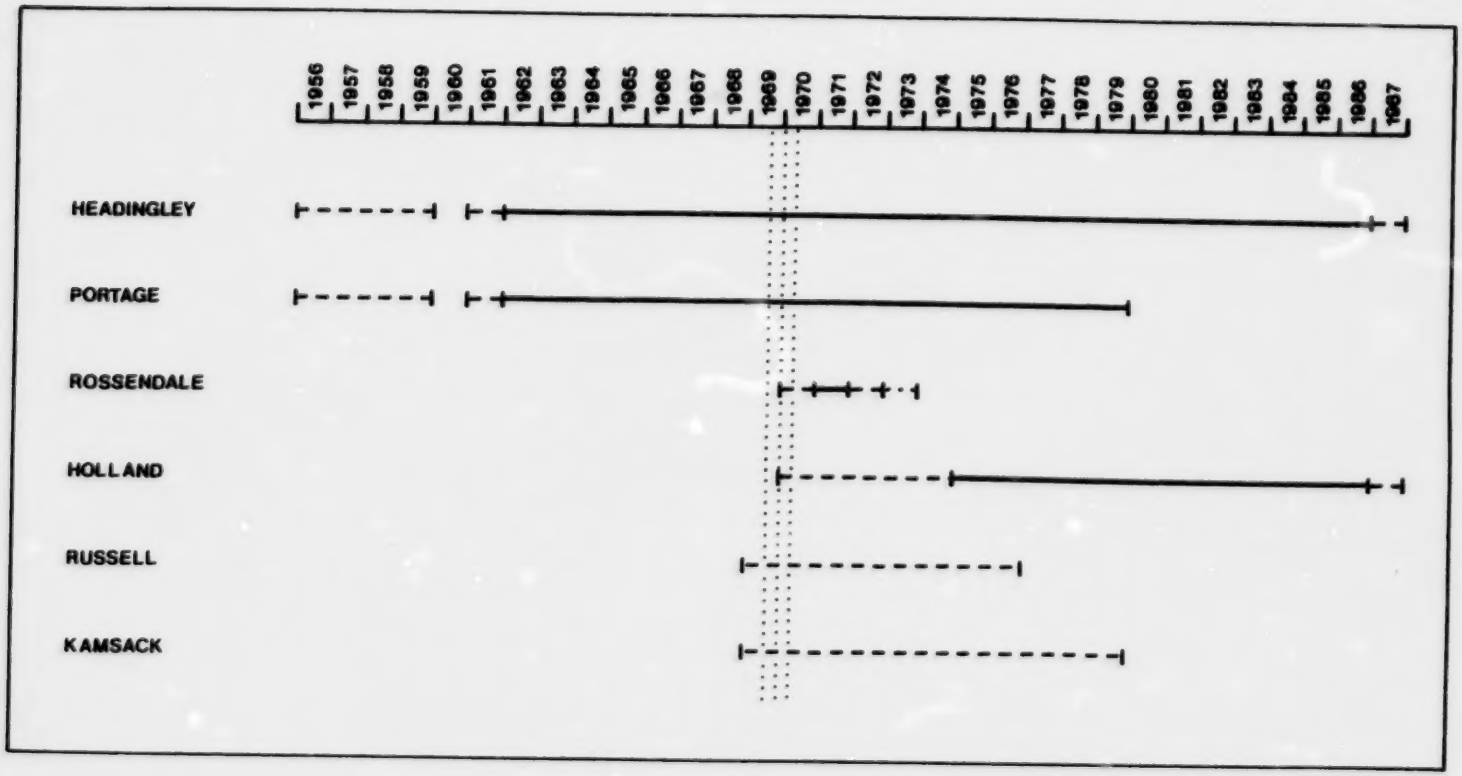


Figure 3 Period of Record of WRB Sediment Stations

TABLE 2 WRB Sediment Programs on the Assiniboine River

Station	Daily Concentration	Daily Load	Particle Size DI	PI	BM
Kamsack	X	X			
Russell	X	X			
Holland	X	X	X	X	X
Rossendale	X	X	X	X	X
Portage la Prairie	X	X	X	X	X
Headingley	X	X	X	X	X

DI = Depth integrating

PI = Point integrating

BM = Bed material

These are the only six stations within the Assiniboine River basin itself. However, there are numerous sediment stations in the Souris and Qu'Appelle basins. In most cases the record is very limited in length and number of samples because the Water Resources Branch in Regina has deliberately operated stations in this way to obtain merely an indication of the range of sediment concentrations in these small tributary streams. Analysis of these records is outside the scope of this report but in Section 11 the contribution of the Souris and Qu'Appelle rivers to the sediment load of the Assiniboine River is considered, based on inspection of the data from some of these stations. The data from the two sediment stations on the Portage Diversion Channel are also discussed in Section 11 in order to establish the quantity of suspended sediment presently routed into Lake Manitoba.

In addition to WRB sediment data Environment Canada, Water Quality Branch has collected water quality data at several sites along the Assiniboine River. These samples include analyses of suspended sediment concentration (non-filterable residue). The samples are few at most sites and the sampling locations do not coincide with WRB sediment stations in most cases, but they do provide more information on sediment concentration in the river. These data are summarized in Section 10.

Summaries of the sediment data collected to date at each of the six WRB sediment stations follow. Subsequent sections integrate this information into an

overview of the sediment yield of the Assiniboine River basin. Each of the station analyses relies primarily on the existing WRB sediment data and the format followed in each case is that established for WRB sediment station analysis reports.

4. ASSINIBOINE RIVER AT KAMSACK (05MD004)

4.1 Station Description and Sediment Program

The sediment station at Kamsack was established in 1969 at an existing hydrometric site, which was a convenient location at which to measure the sediment loads into the newly constructed Lake of the Prairies (Shellmouth) reservoir. The station is located 0.5 km downstream of the confluence with Whitesand River west of Kamsack and 90 m upstream of the Hwy. 5 bridge. The cableway, which is used at high flow, is constructed on the old bridge abutments at the gauge location.

Full cross-section sediment samples were collected from the cableway once or twice per year. Depth integrated samples were obtained routinely at a single vertical from the Hwy 5 bridge and occasionally by wading 200 m upstream of the gauge. The hydrometric station has used 16 rating curves in 39 years, indicating some problems with cross-section stability. Other problems recorded in the station notes include control by the present highway bridge at high stage and backwater from the Shellmouth reservoir when it is close to full supply level and/or river stage is low. This backwater effect also causes hysteresis in the rating curve and a variable slope at the gauging site. The Assiniboine River at Kamsack is affected by flow regulation on Whitesand River by the Theodore Dam (1958), and to a lesser extent by the town reservoir at Kamsack, located just upstream of the Whitesand junction.

The morphology of the Assiniboine River and valley at Kamsack is typical of much of its course as far downstream as Brandon. The tortuous meanders of the river are confined within a glacial spillway 20 - 25 m deep with a broad floodplain varying in width from 0.5 to 3km. The valley sides are dissected by numerous small intermittent streams and greatly affected by slumping. The stream abuts the valley side only occasionally. Flooding of the valley bottom is a common occurrence around Kamsack, partly due to Shellmouth reservoir backwater.

A seasonal program was maintained at the sediment station from 1969 to 1979. In 1980 it was changed from a full sediment station to a 'special event' station. As in the case of other WRB sediment stations, sampling frequency is flow weighted. At Kamsack samples were collected daily or twice daily during peak flow, and weekly during low flow periods. During the 10 years of station operation, over 600 depth integrated samples were collected with a strong weighting towards the spring snowmelt flood. Figure 4 shows the number of samples collected over each 10% increment of the flow duration curve, from which it is apparent that 463 of 614 samples (76 %) were collected at flows of less than 30% duration. The data collection program operated seasonally, usually commencing in early April with the initial rise in the annual hydrograph and finishing at the end of October. K factors ranged from 0.96 to 1.04 indicating negligible lateral variation in concentration at the cableway.

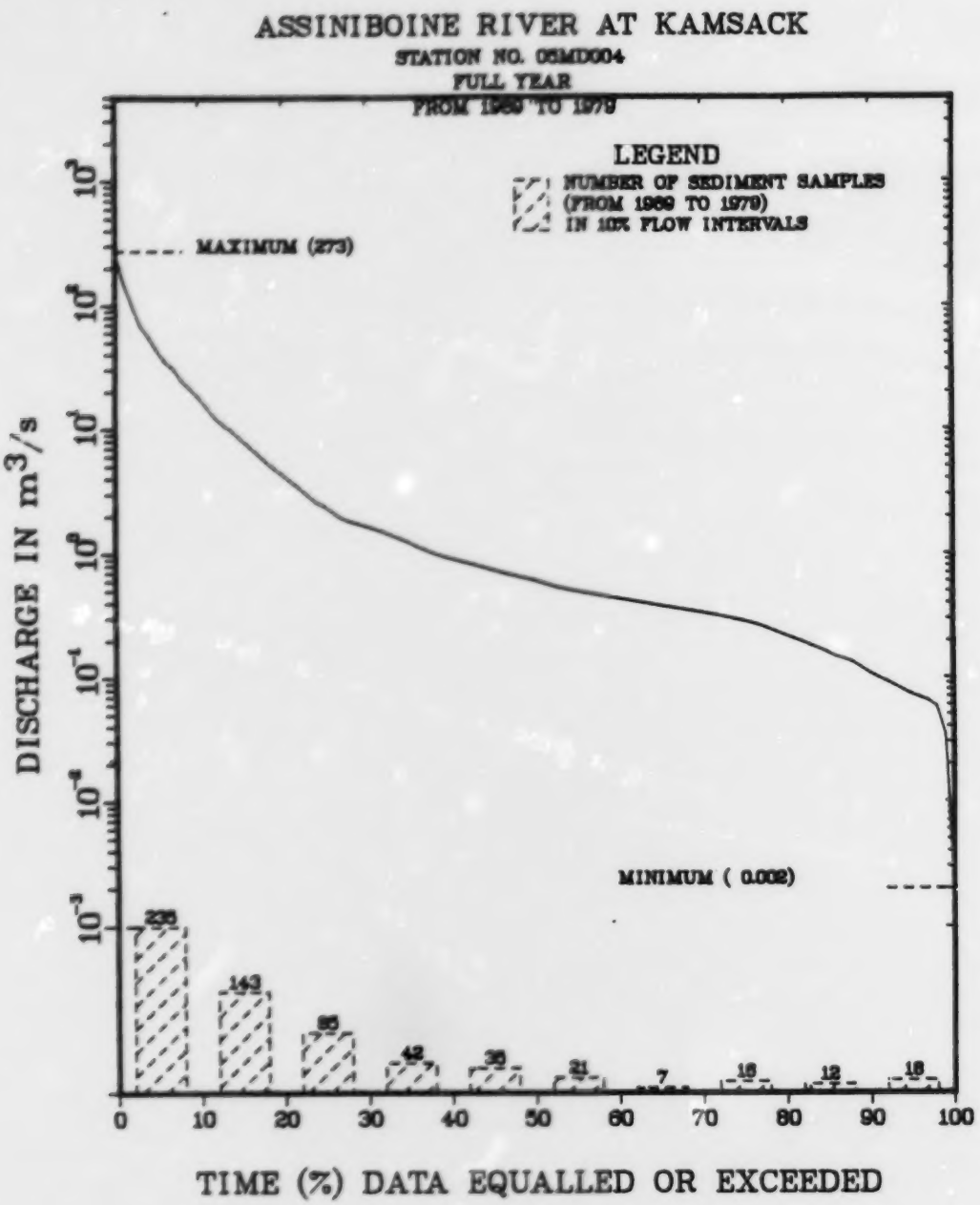


Figure 4 Frequency of Sediment Sampling: Kamsack

4.2 Flow Coverage

The maximum sampled discharge of 273 m^3s^{-1} in 1976 is the maximium daily discharge on record (since 1944) at this station. Similarly, the low flow coverage extends to the minimum recorded flows. Figure 5 shows the maximium daily and total annual discharges for the entire flow record since 1944 and confirms that the years 1969 to 1979, when sediment sampling was carried out, cover the full range of discharges. In particular, the years of sediment sampling include the five highest total annual and annual maximum discharges.

4.3 Annual Discharge and Sediment Regime

Annual mean discharge at Kamsack is 5.26 $m^3 s^{-1}$. The average annual flow and sediment regimes, together with examples from particular years, are shown in Figures 6 and 7. The discharge regime is typical of streams fed entirely by prairie runoff. The hydrograph begins to rise quickly in mid-April to a peak in late April or early May. There is a slight tendency towards a double peak, perhaps because of differences in timing between the Whitesand and Assiniboine rivers. After this initial snowmelt flood, discharge generally declines steadily through the summer, apart from occasional summer storms (e.g. July, 1976). These summer storms may be significant runoff events [and hence significant sediment transport events in low snow cover years (e.g. 1973)], but on average they are secondary to the snowmelt flood. Prairie

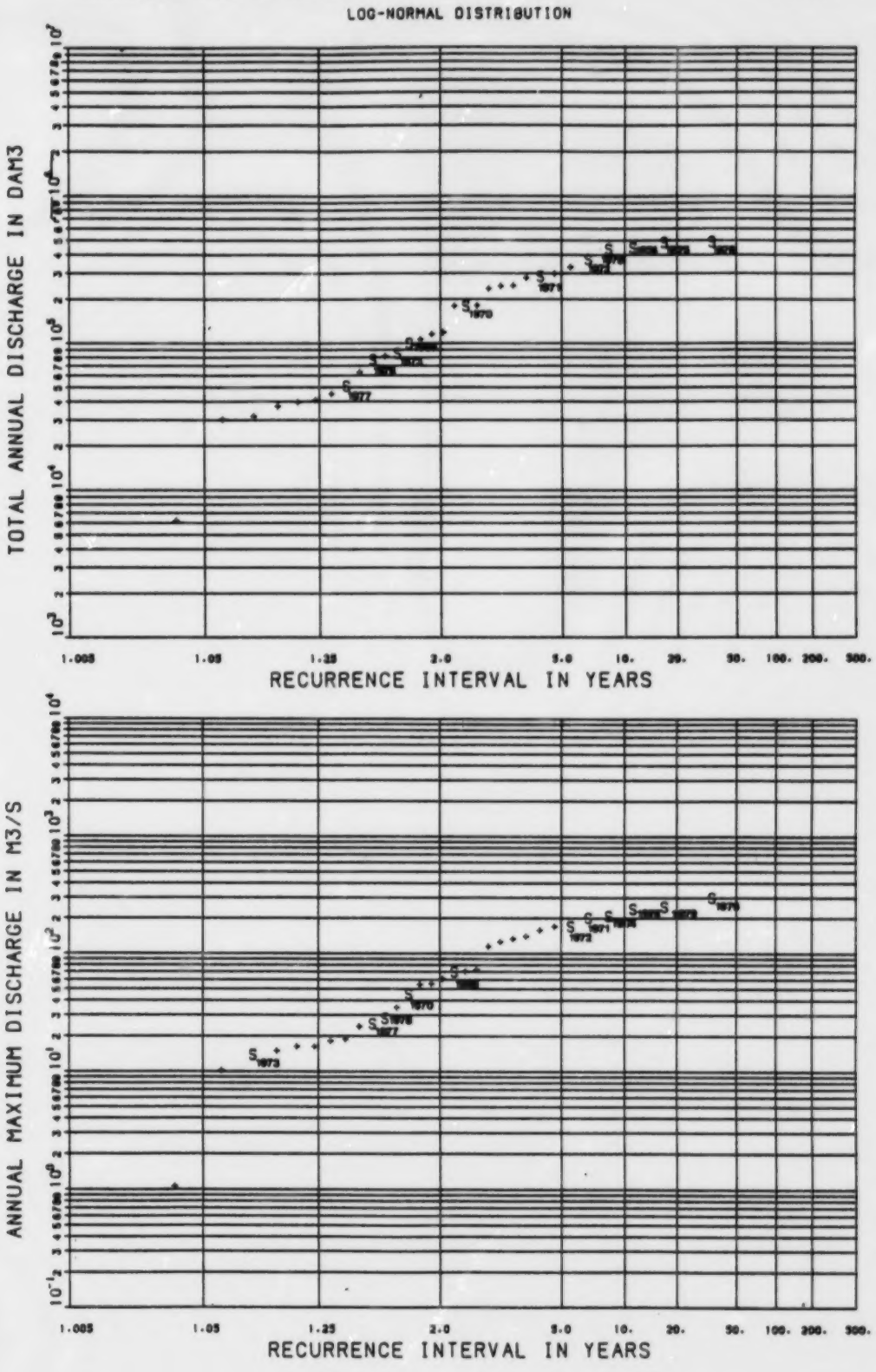


Figure 5 Coverage of Extreme Discharges: Kamsack

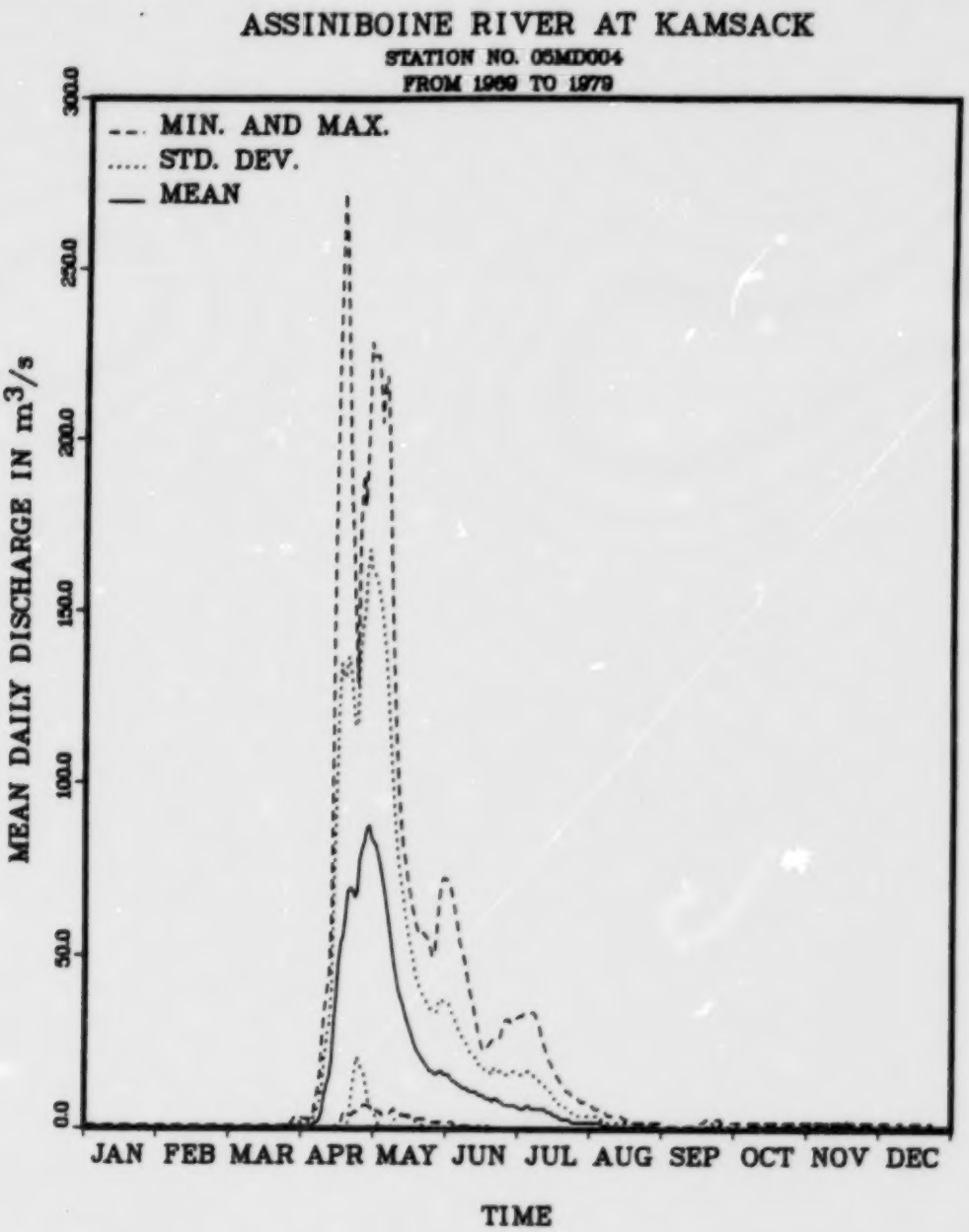
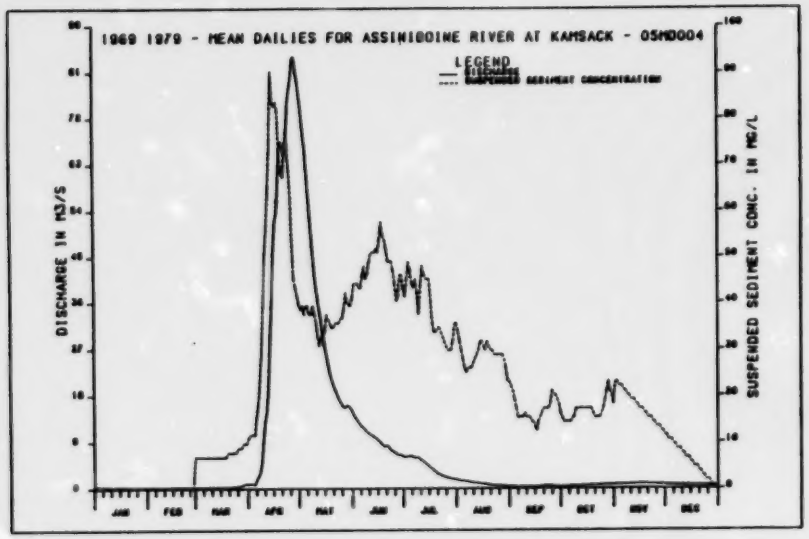
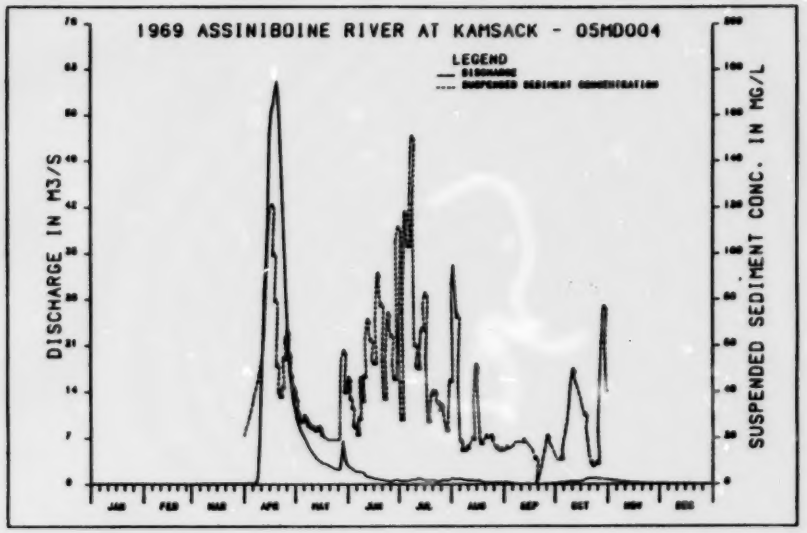
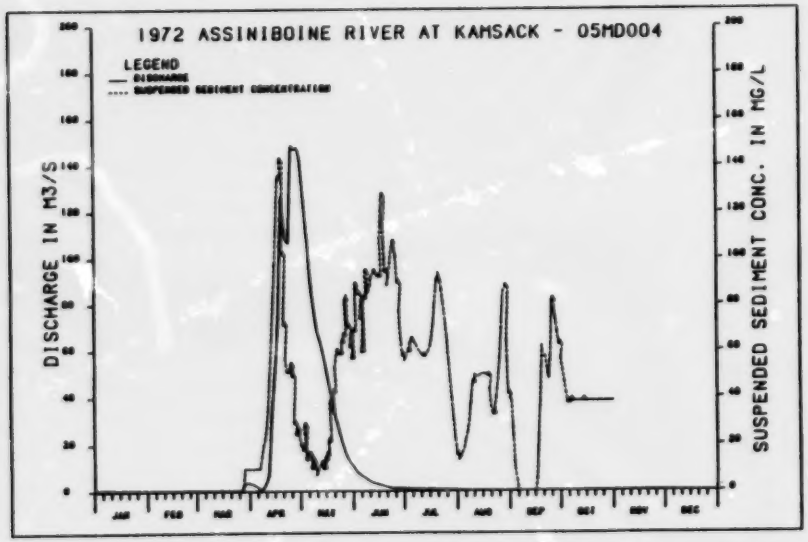


Figure 6 Average Annual Hydrograph : Kamsack


1969 1979 - MEAN DAILIES FOR ASSINIBOINE RIVER AT KAMSACK - 05MD004
LEGEND
DISCHARGE IN M3/S
SUSPENDED SEDIMENT CONC. IN MG/L





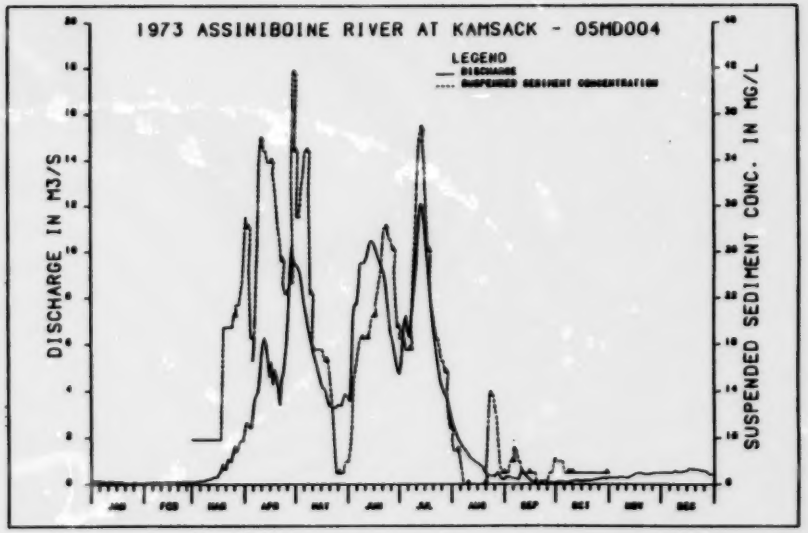
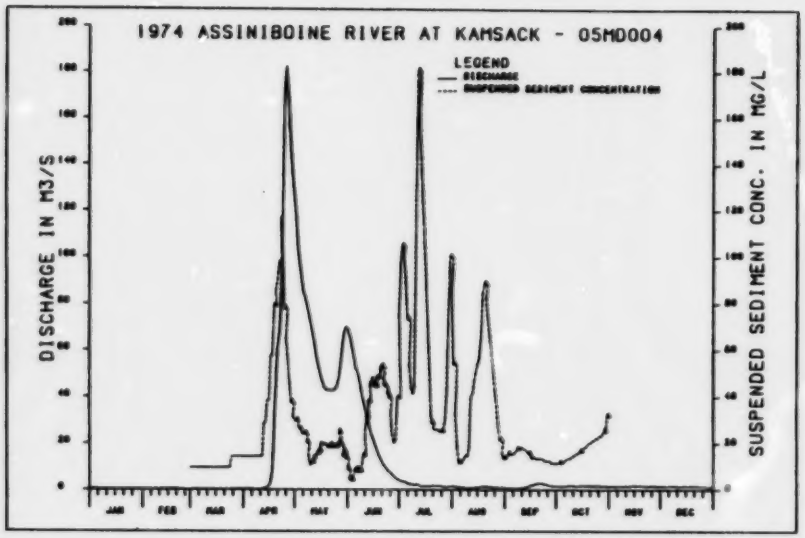
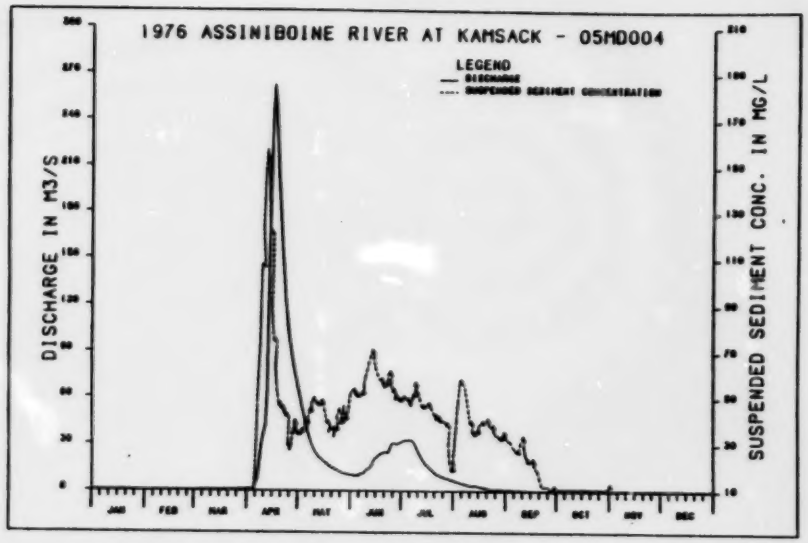


Figure 7 Examples of Annual Discharge and Sediment Regimes: Kamsack





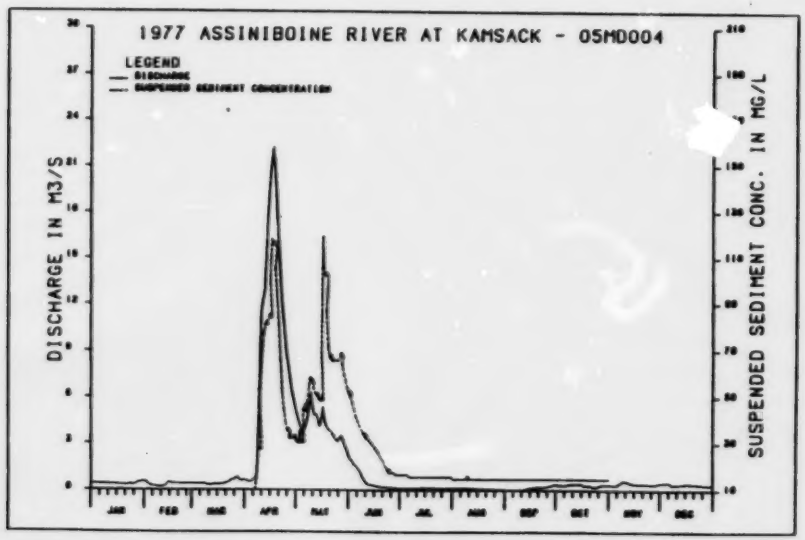


Figure 7 Continued

Provinces Water Board (1982) suggest that the discharge regime at Kamsack has not been altered significantly by upstream flow regulation.

The annual sediment concentration regime follows that of discharge in having a peak in late April or early May and declining through the summer and fall (e.g. 1976). The sediment concentration peak usually coincides with, or precedes slightly, the discharge peak, but declines more rapidly than the discharge peak. L. Heinze (pers. comm. 1989) suggests that the early rise in sediment concentration is attributable to soil erosion of cultivated fields on west-facing slopes just north of Kamsack. Sediment concentrations during the spring flood usually peak at between 120 and 180 mg l^{-1}.

Apart from the expected pattern of variation in suspended sediment concentrations, the annual hydrographs also reveal some peculiarities in the sediment regime during the summer. The sediment concentrations during these summer runoff events are often quite high and, at times, higher than those of the spring freshet (e.g. 1969, 1974, 1977). There are also examples of summer concentration peaks which seem to bear no relation to fluctuations in discharge (e.g. 1969, 1972, 1974). One possible explanation of this peculiarity is that the sampler collected bottom sediment that it had disturbed during low flow when velocities were extremely low (L. Heinze, pers. comm. 1989).

The result of the rapid drop in sediment concentration after the spring flood peak is a general clockwise hysteresis in sediment concentration during the freshet (Figure 8). This is apparent in the daily concentrations as well as the monthly averages. The hysteresis pattern becomes more erratic in the summer, for the reasons discussed in the previous paragraph. In several years the pattern is chaotic.

4.4 Daily Mean Suspended Sediment Concentration

The erratic behaviour of summer suspended sediment concentrations is reflected in the daily mean suspended sediment rating plots. The year to year variation in the least squares linear regression equations is enormous and the correlation between suspended sediment concentration and discharge is very poor in some cases. The slopes of the best fit regression lines vary from 0.390 to -0.105 and R^2 varies from 0.12 to 0.87 but is generally in the range 0.4 to 0.6. In other words the annual suspended sediment rating curves are very poor. The data for all years combined are shown in Figure 9.

When all data are combined, the concentration at a given discharge scatters over two orders of magnitude around the best fit regression line. The slope on the regression line is 0.101 and may not be significantly different from zero. In short, predictions of sediment load based on the existing relationship between suspended sediment concentration and discharge would be very suspect. In most circumstances

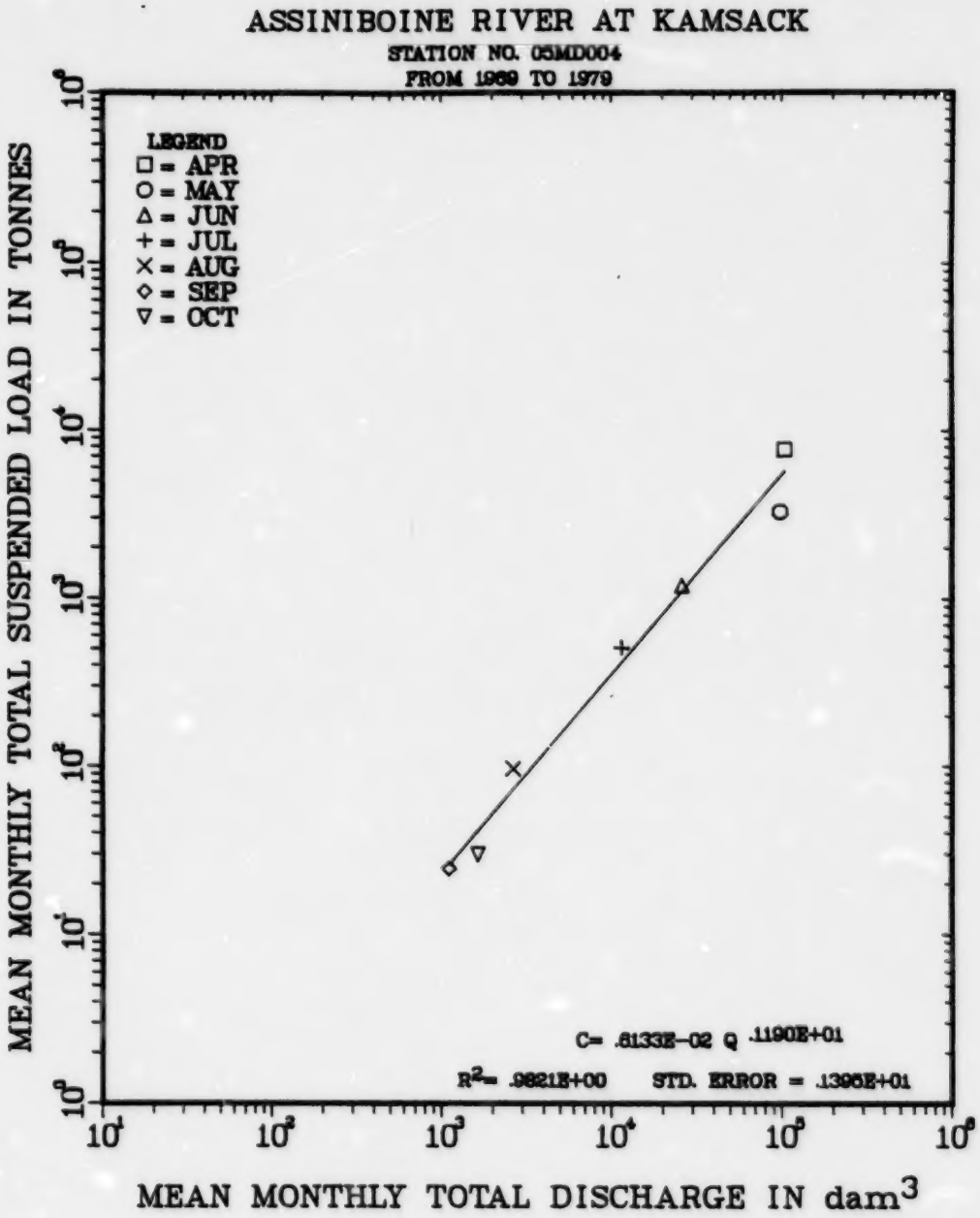


Figure 8 Mean Monthly Load versus Mean Monthly Discharge: Kamsack

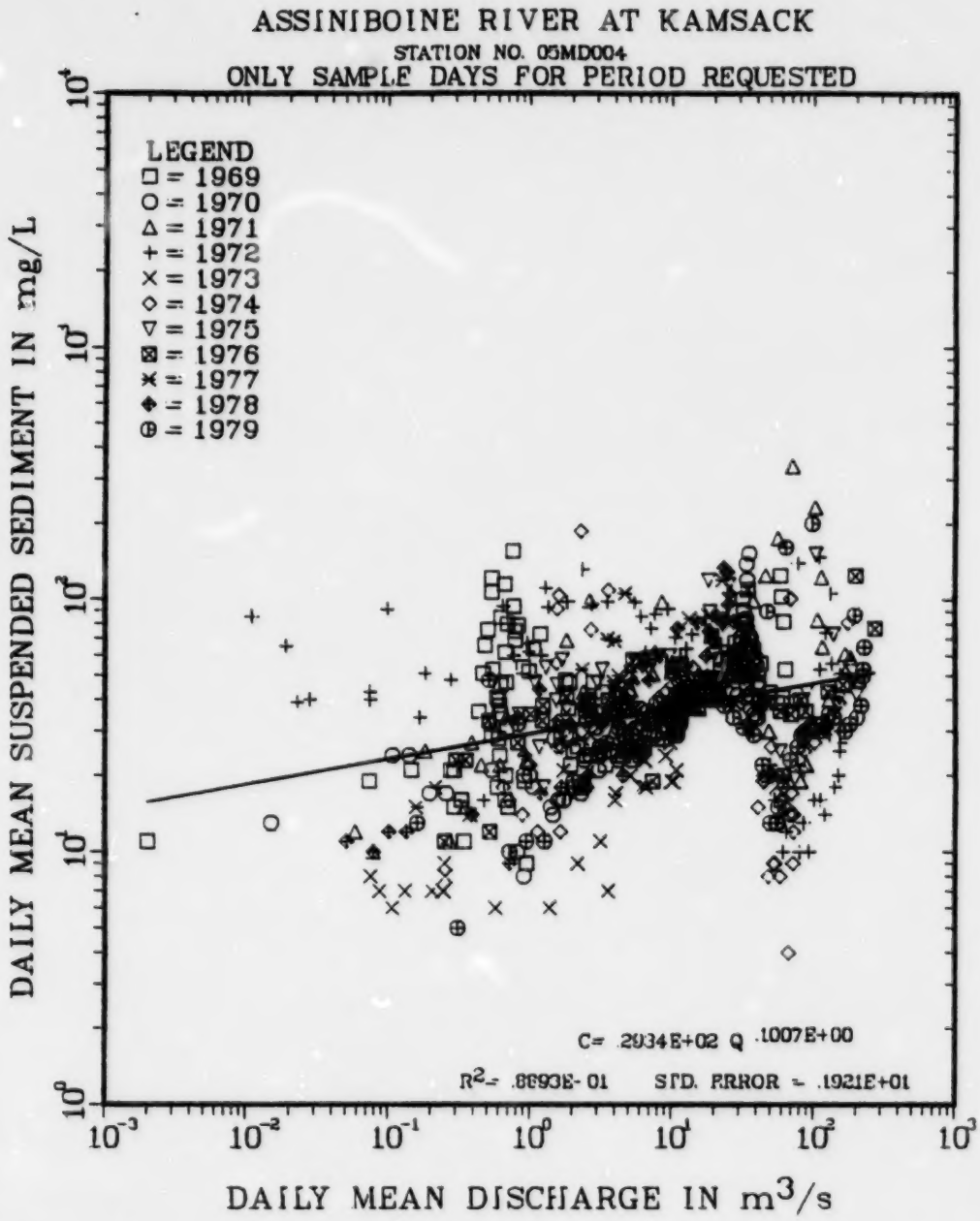


Figure 9 Daily Mean Suspended Sediment Concentration versus Discharge: Kamsack

where this is the case it is because the suspended sediment load is dominated by wash load, which is controlled by supply to the river rather than hydraulic conditions in the river itself.

4.5 Suspended Sediment Concentration and Load

Figure 10 shows the duration curves of daily suspended sediment concentration and load at Kamsack for the period (March - December, 1969-1979). Maximum recorded concentration is 338 mg l^{-1}, the median is 24 mg l^{-1} and concentrations of 300 mg l^{-1} and 100 mg l^{-1} are equalled or exceeded about 1% and 4% of the time respectively. Maximum recorded daily load is 2 140 Mg, the median is 2.7 Mg and daily load of 1 000 Mg is equalled or exceeded less than 1% of the time.

On average, 80 % of the load is carried in only 13% of the time (Fig. 11). The most "effective" discharge range (defined as the discharges which transported the largest cumulative load during the period of record) for sediment transport is 17 to 33 $m^3 s^{-1}$; a discharge exceeded between 6 and 10% of the time (Fig. 11). The average maximum loads for 10% (24 days) and 1% (2 days) of the season (April- October) are 68% and 15% of the total seasonal load respectively (Fig. 12).

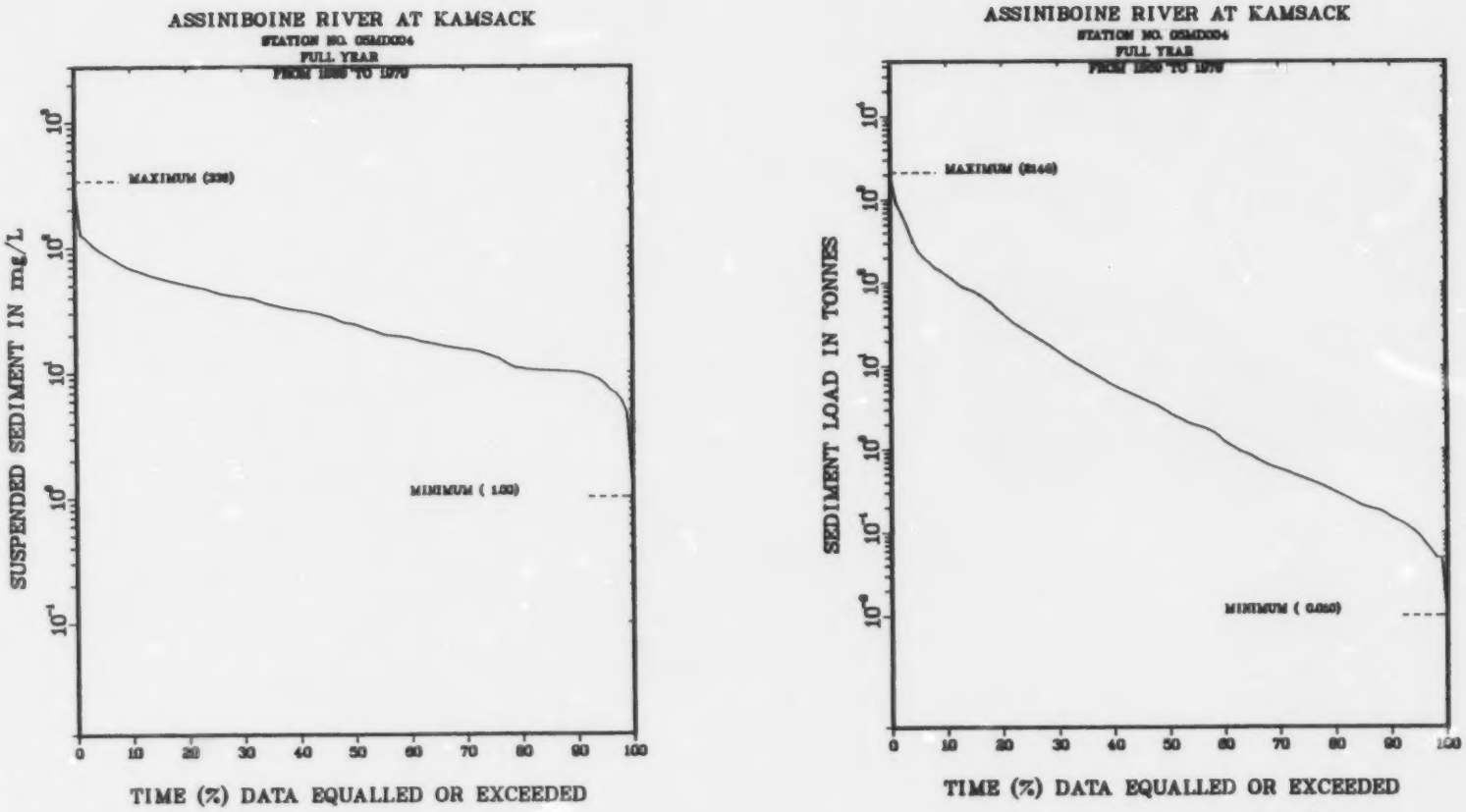


Figure 10 Daily Concentration and Load Duration Curves: Kamsack

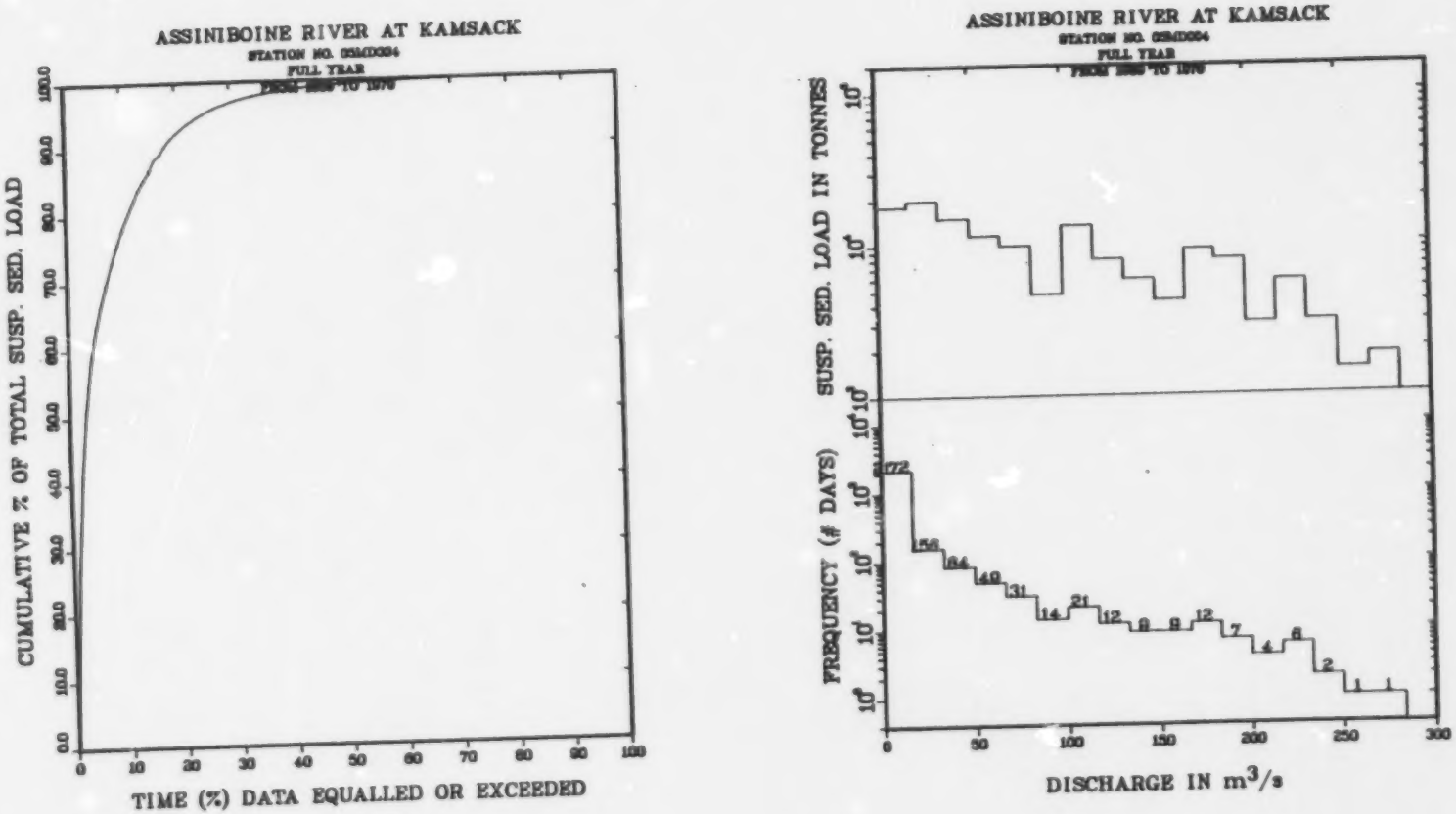


Figure 11 'Effective' Discharge and Cumulative Load Duration Curve: Kamsack

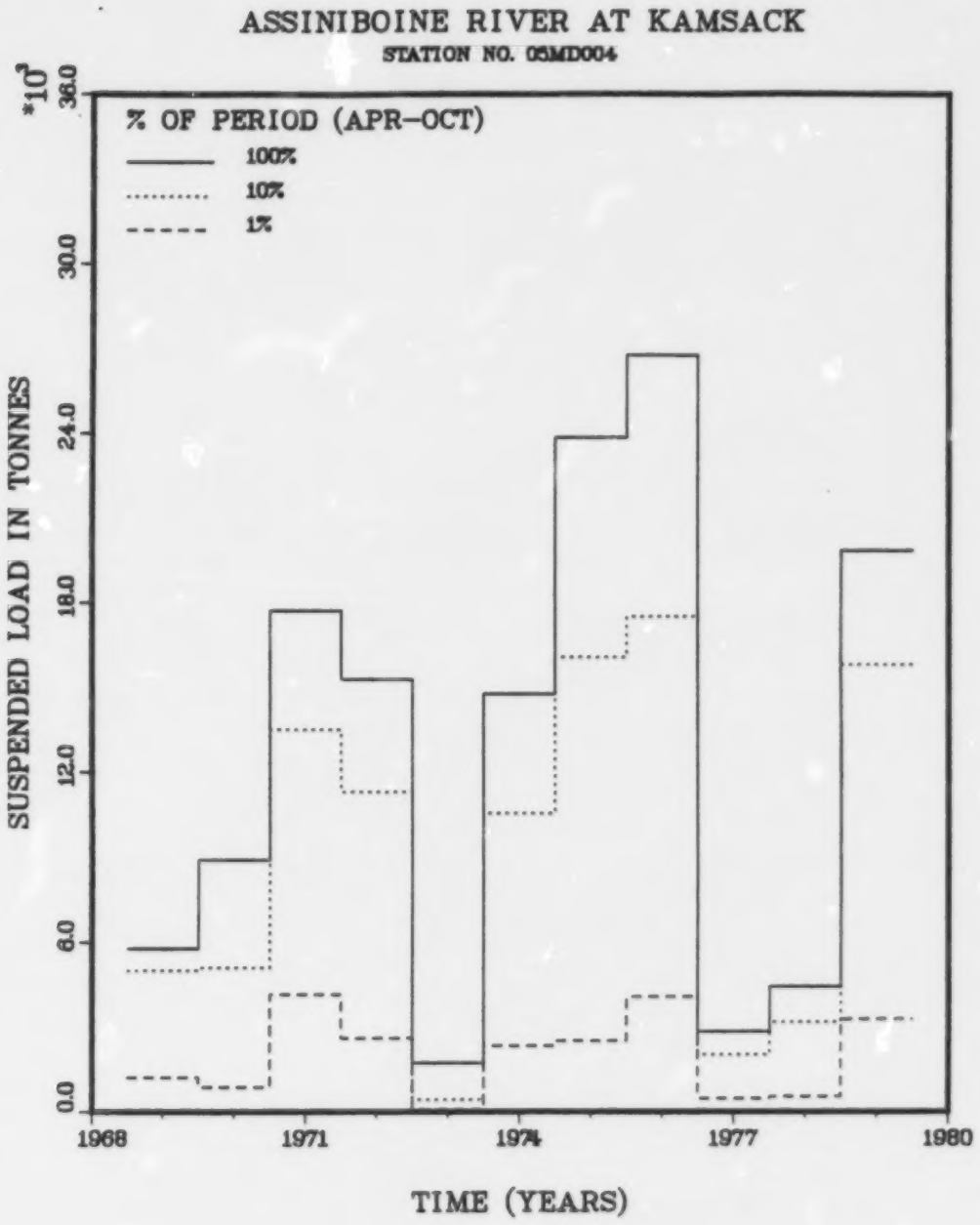


Figure 12 'Best Percent' of the Seasonal Load: Kamsack

4.6 Total Annual Load and Yield

Total seasonal loads vary from 1 741 to 26 799 Mg, with a mean of 12 910 Mg and a standard error of 21.3% of the mean. Assuming that the winter load is negligible (monthly mean discharges in winter are less than 1 $m^3 s^{-1}$), these are reasonable estimates of the total annual load. The relationship between seasonal load and total seasonal discharge is consistent, with no obvious anomalies, although the correlation between seasonal discharge and average seasonal concentration is not particularly strong (Figure 13). The standard error of the estimate of the mean seasonal sediment load has not declined substantially over the 10 year record, and hardly changed at all during the last 5 years. It is likely that sediment stations near the headwaters of these prairies streams need very long records to establish mean annual loads with standard errors of less than 10% - an effort which would not be worthwhile for most practical purposes.

Mean seasonal discharge during the period of sediment record was 246 000 dam^3. This gives an average annual flow weighted concentration (seasonal load / seasonal flow) of 52 mg l^{-1}. Generally speaking, the years 1969 to 1979 had discharges above average compared with the complete period of flow record at this station (Fig. 14), thus the load estimates may be overestimates compared with stations with records covering the 1960s.

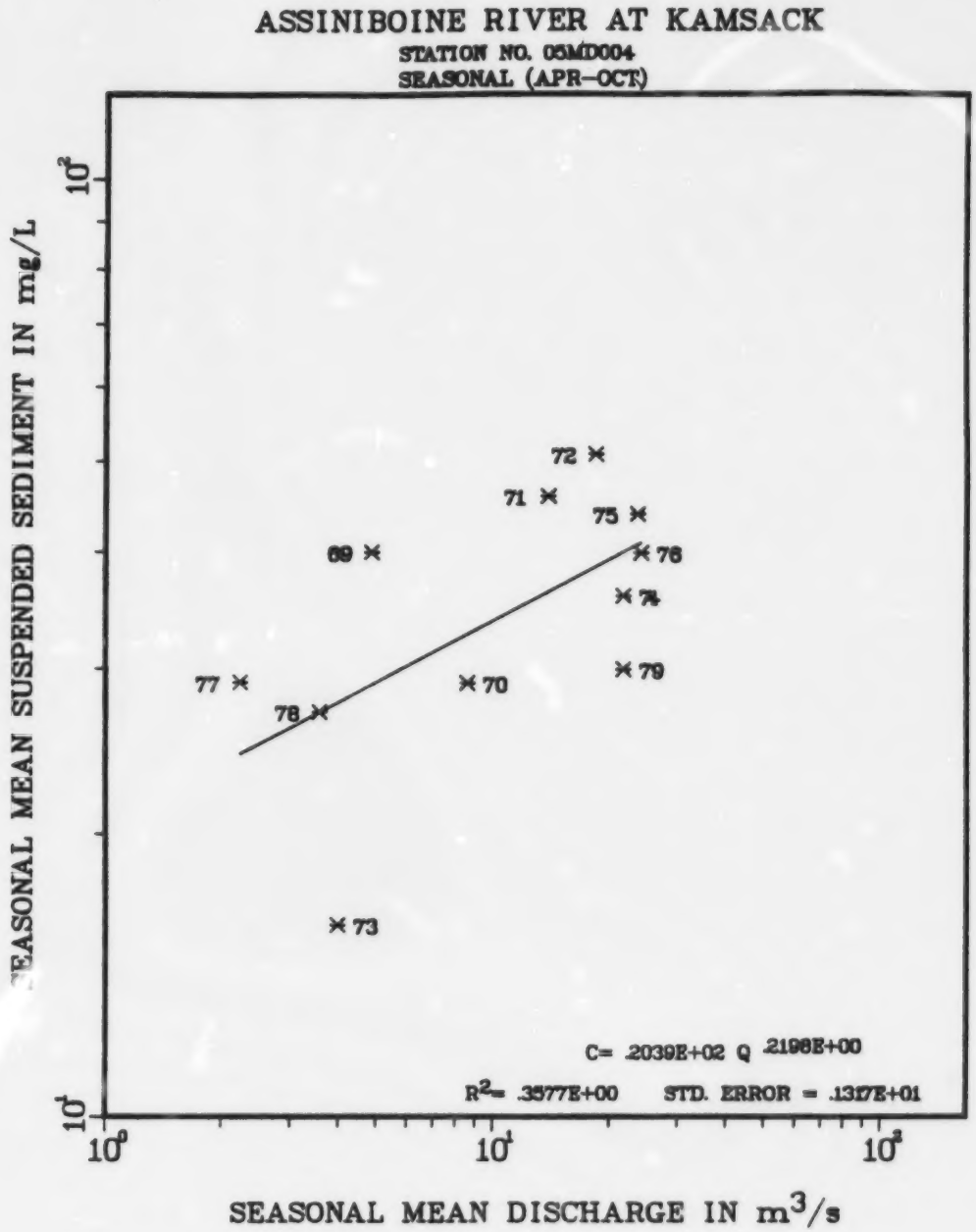


Figure 13 Seasonal Mean Suspended Sediment Concentration versus Seasonal Mean Discharge: Kamsack

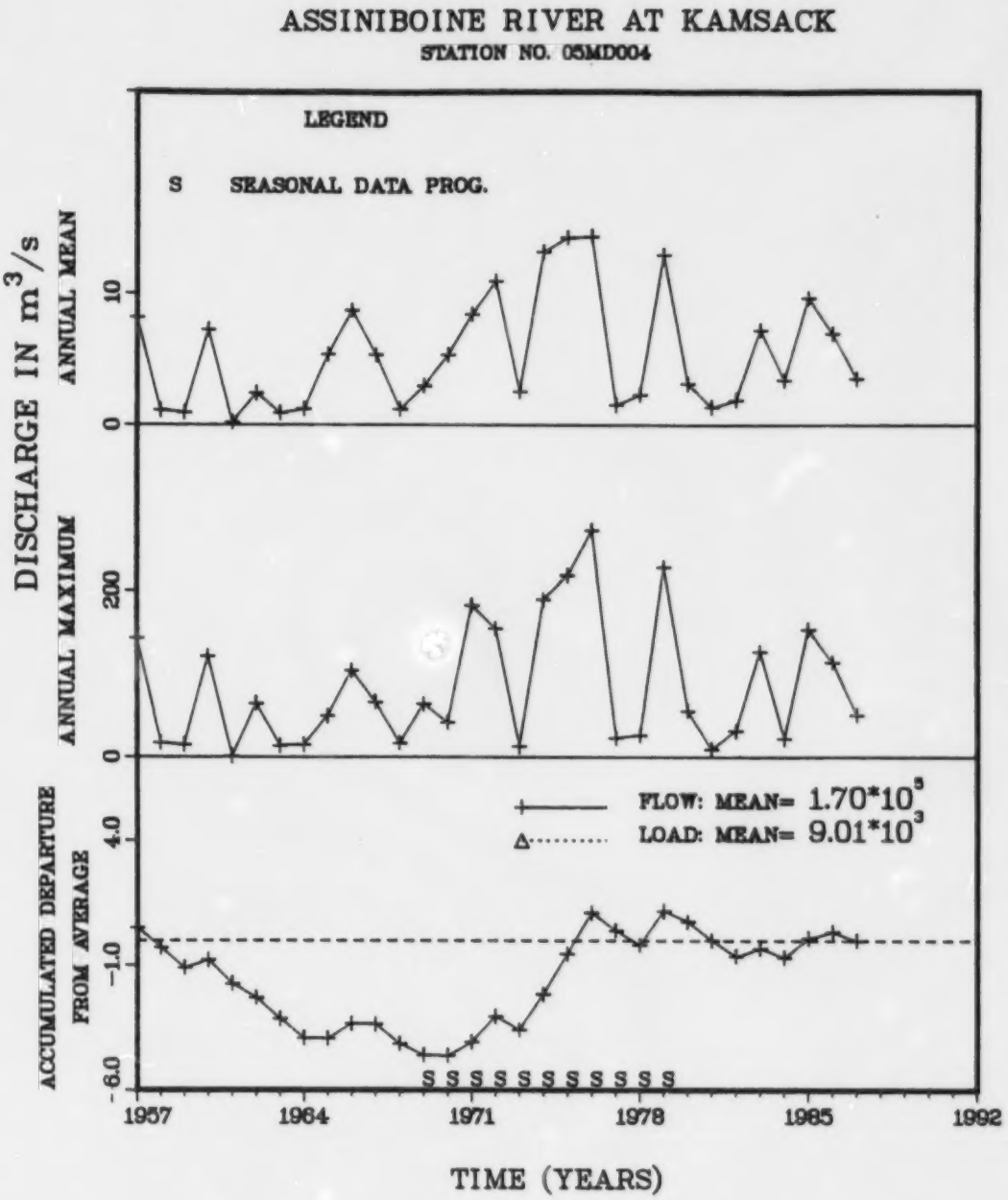


Figure 14 Flow History: Kamsack

5. ASSINIBOINE RIVER NEAR RUSSELL (05ME001)

5.1 Station Description and Sediment Program

The WRB sediment station near Russell was established in 1969 to assess the downstream impact of Lake of the Prairies (Shellmouth reservoir) on the sediment regime of the Assiniboine River (Yuzyk and Penner, 1988). A seasonal sediment data collection program was run from 1969 to 1976. The sediment station utilized an existing hydrometric station that had been operating at various times since 1913, and continuously since 1951. The hydrometric measurements continued after cessation of the sediment program. The current location of the station was established in 1959 at the old Hwy. 4 bridge crossing 11 km west of Russell, a few kilometres upstream of the present Hwy 16 bridge. This is immediately downstream of the junction with Conjuring Creek, which has deposited a small sand bar near the left bank of the channel upstream of the bridge. The shelter is located on the west side (right bank) of the river downstream of the bridge. Measurements are made either from the bridge rail or by wading.

The river and valley morphology at this station are very similar to that at Kamsack. The river still has a meandering pattern, although the meanders are generally less tortuous than at Kamsack. The spillway morphology is also very similar although deeper than at Kamsack (floodplain width of 0.75 km and a valley depth of 80 - 85m). Gross drainage area above Russell is 19 298 km^2 and effective drainage

area is 7 664 km². However, the area yielding sediment to this portion of the river is probably restricted to the basin downstream of the Shellmouth Dam (1 460 km²) because the trapping efficiency of the reservoir is over 90% (Oshoway, 1984).

The sediment program at Russell has been restricted to conventional depth-integrating sediment concentrations and load estimates. There are no particle size data or point-integrating samples. The suspended sediment sampling has followed a standard flow-weighted scheme. There are a total of 859 samples collected in 8 years, of which 507 (59%) were collected during flows equalled or exceeded 30% of the time (Fig. 15). Data collection was seasonal, beginning in early April and continuing to the end of October, or, in some years, into November. In the last few years of the program (1973 - 76) sampling was extended to cover the full year. The record for 1969 covers only May and June and missed the snowmelt freshet in April.

5.2 Flow Coverage

The seasonal sampling scheme was successful in sampling the peak discharges in all years except 1969. The sampled discharges cover most of the flow duration curve. Because the sediment station was established after flow regulation by the Shellmouth Dam was established, the extreme flows of record, occurring before the construction of the dam, were not sampled. The regulated regime shows a much reduced flow range. However, the coverage of post reservoir flows (1970 - 1986) is good (Figure 16). The

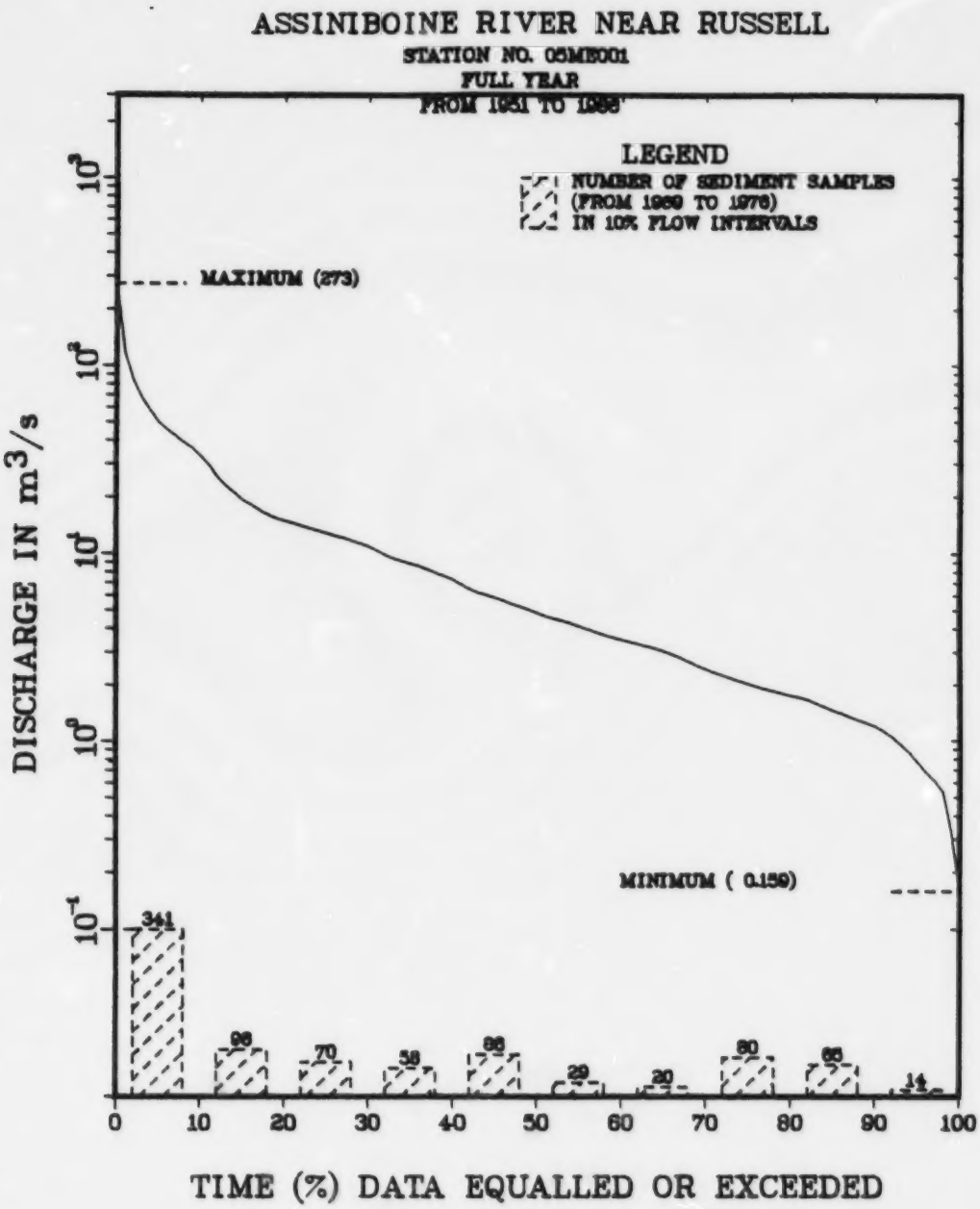


Figure 15 Frequency of Sediment Sampling: Russell

sediment data cover a reasonable range of flow extremes and, in particular, include the three highest annual maximum and annual total discharges for the period 1970 to 1986.

5.3 Annual Discharge and Sediment Regime

Annual mean discharge at Russell is 12.3 m^3s^{-1} (1970-1986). Until construction of Shellmouth Dam, the Assiniboine River near Russell had a conventional prairie flow regime (Figure 17). Discharge peaked in late April or early May and declined thereafter apart from occasional large summer storms. Since the construction of the Shellmouth Dam the flow regime has been substantially modified (Figure 17); peak flows continue to occur in the spring, although two or three weeks later than they would naturally. This reflects the flood control function of the Lake of the Prairies. Winter flows are now substantially augmented as well. Prairie Provinces Water board (1982) calculate that current flows at Russell are a few percent lower than the natural flow. More importantly, the April peak flows are only about 10% to 20% of natural flow, May discharges are about 70 to 80% of natural, and the winter flows (November to March) are five to ten times higher than natural. Flows in June and July are also augmented slightly.

Figure 18 shows examples of the annual flow regime together with the graph of the average annual flow and sediment regime for the period of sediment data

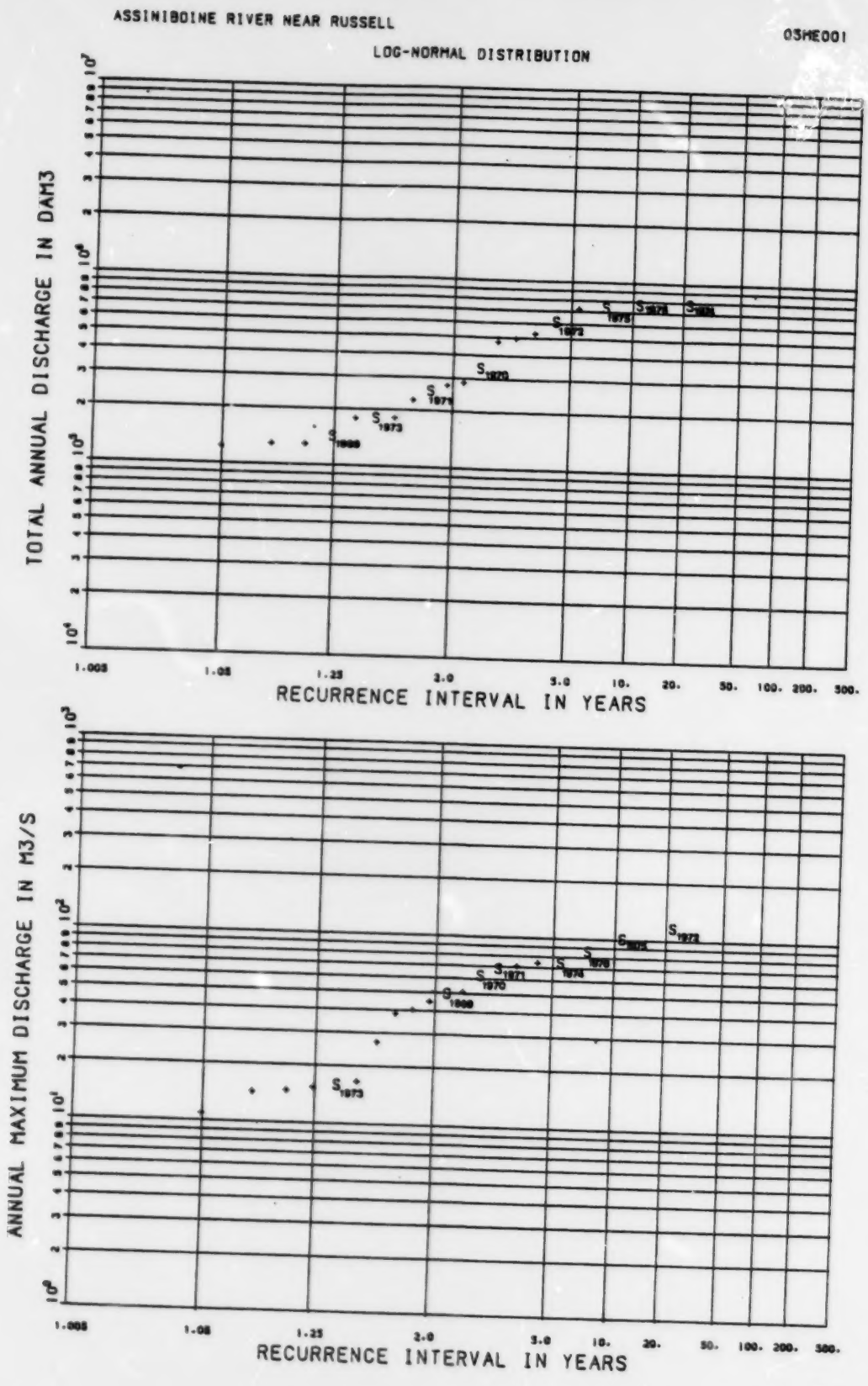


Figure 16 Coverage of Extreme Discharges: Russell

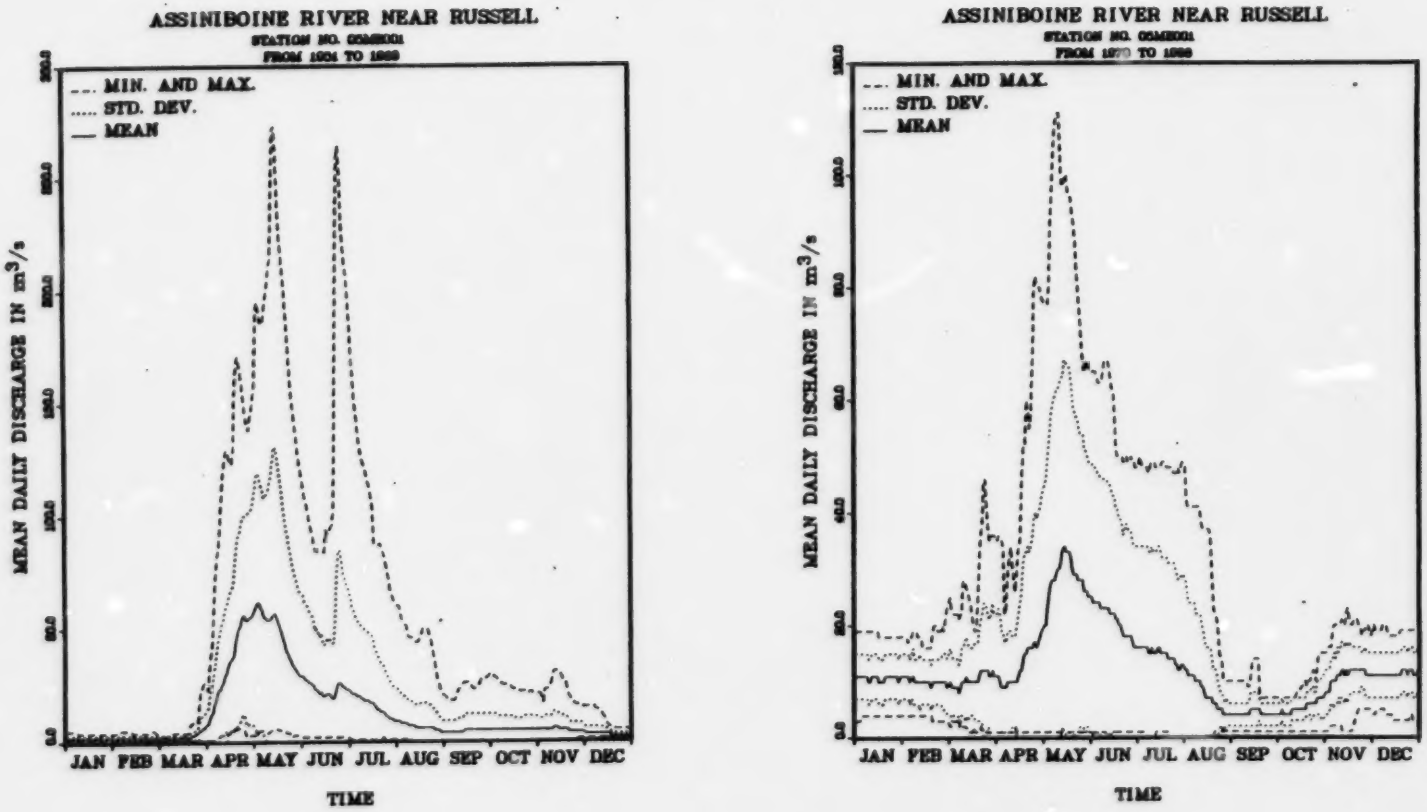
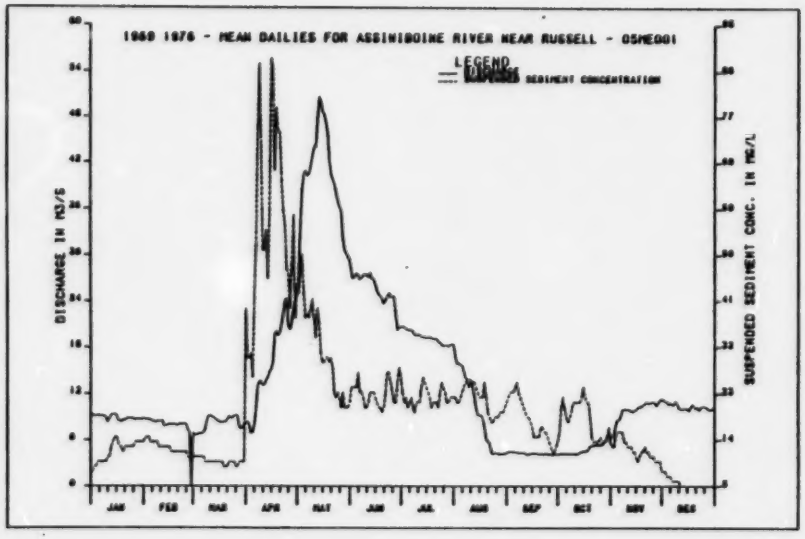
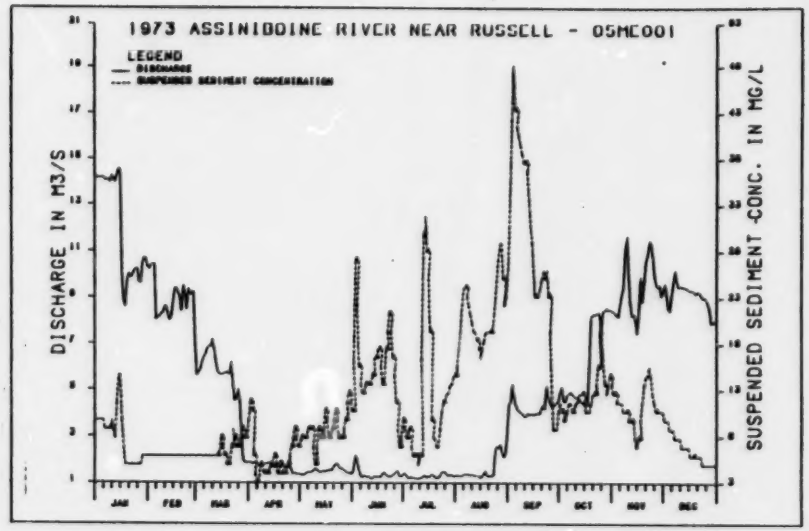
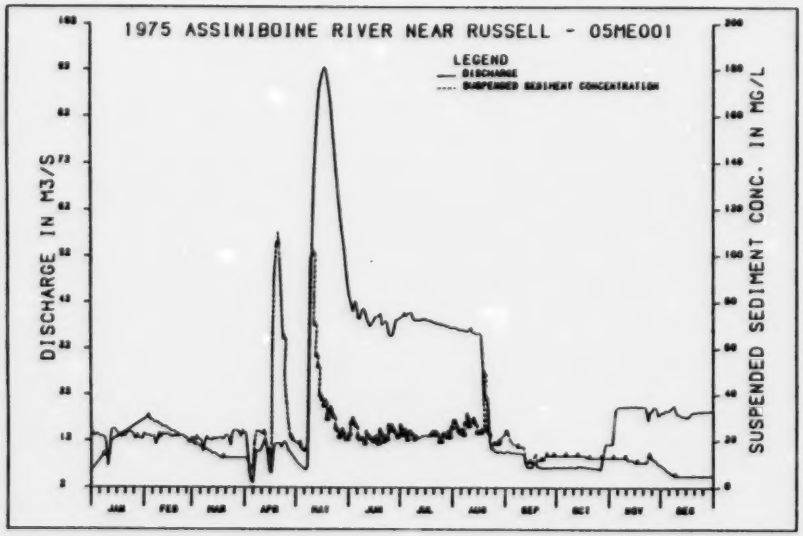

ASSINIBOINE RIVER NEAR RUSSELL
--- MIN. AND MAX.
..... STD. DEV.
— MEAN
MEAN DAILY DISCHARGE IN m3/s
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME
ASSINIBOINE RIVER NEAR RUSSELL
--- MIN. AND MAX.
..... STD. DEV.
— MEAN
MEAN DAILY DISCHARGE IN m3/s
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME

Figure 17 Effect of Shellmouth Dam on the Annual Hydrograph: Russell


1960 1976 - MEAN DAILIES FOR ASSINIBOINE RIVER NEAR RUSSELL - 05ME001
LEGEND
DISCHARGE IN M3/S
SUSPENDED SEDIMENT CONC. IN MG/L





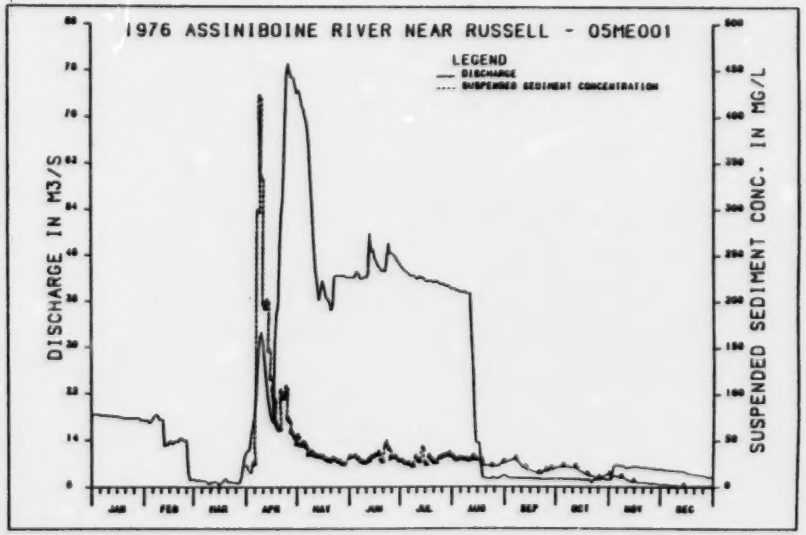


Figure 18 Examples of Annual Hydrographs and Sediment Regimes: Russell

collection. In most years the April flood peak is almost completely suppressed and instead peak flows occur in mid-May. Reservoir releases maintain June and July discharges at a fairly constant level until the reservoir is drawn down. The low flows of late summer and fall are followed by higher winter flows. This is the general pattern for all years of the sediment record, except 1973 when spring and summer flows were a small fraction of normal (< 2 m^3 s^{-1} instead of 50 to 100 m^3 s^{-1}) and peak flows occurred during the winter months instead.

The sediment regime has also been modified by flow regulation (Fig. 18). Peak sediment concentrations often occur in late April, rather than coinciding with the May discharge peak. Presumably this is sediment supplied from sources downstream of the reservoir, such as local bank erosion, and tributary streams and gullies. An increase in sediment load also occurs in conjunction with the May discharge peak, but the summer and winter reservoir releases generally have very low sediment concentrations. The result of this local sediment supply independent of reservoir releases is apparent in the graph of average monthly concentration versus average discharge which shows obvious clockwise hysteresis (Fig. 19).

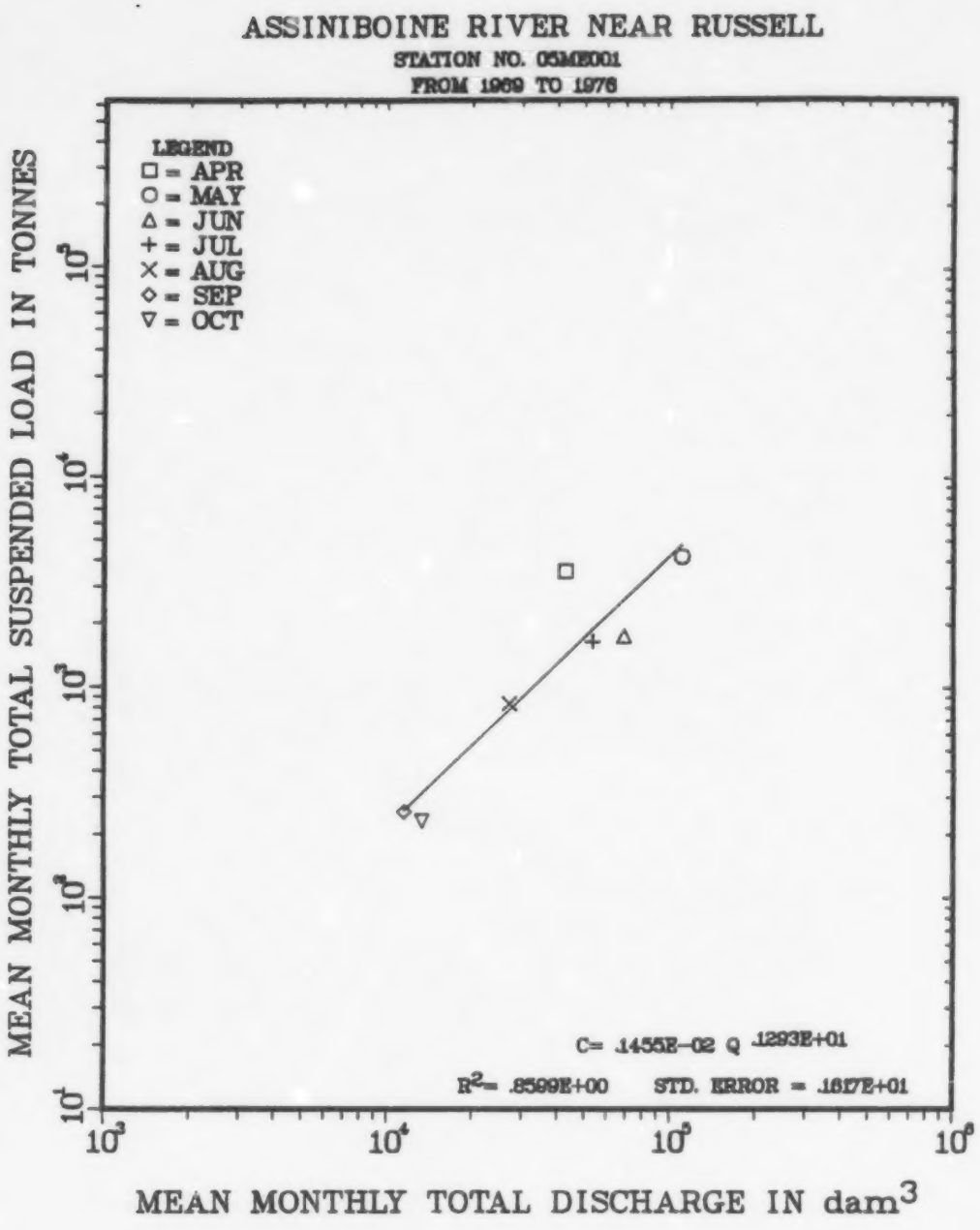


Figure 19 Mean Monthly Suspended Sediment Load versus Mean Monthly Discharge: Russell

5.4 Daily Mean Suspended Sediment Concentration

Figure 20 shows the mean daily suspended sediment rating curve for the full period of record. The low standard error and R^2 value, together with a greater than order of magnitude variation in concentration at a given discharge, are indicative of a very poor rating relationship in a stream dominated by wash load rather than suspended bed material load.

5.5 Suspended Sediment Concentration and Load

The duration curves for daily suspended sediment concentration and load are shown in Figure 21, for the period April-October, 1969-1976. The maximum recorded concentration is 437 mg l^{-1}, the median is 23 mg l^{-1} and concentrations of 300 and 100 mg l^{-1} are exceeded less than 1% and 3% of the time respectively. This is very similar to the concentration range at Kamsack. Daily loads range from 0.15 to 1 220 Mg, the median is 15 Mg, and a daily load of 1 000 Mg is exceeded less than 1% of the time.

On average, 80% of the seasonal load is transported in 25% of the time, and the "effective" discharge range is 47-53 $m^3 s^{-1}$, which has a duration of 5-6 % on the annual flow duration curve (Fig. 22). The average maximum loads for 10% (24 consecutive days) and 1% (2 consecutive days) of the season are 39% and 9% of the seasonal load respectively (Fig. 23). These are both lower than the values for

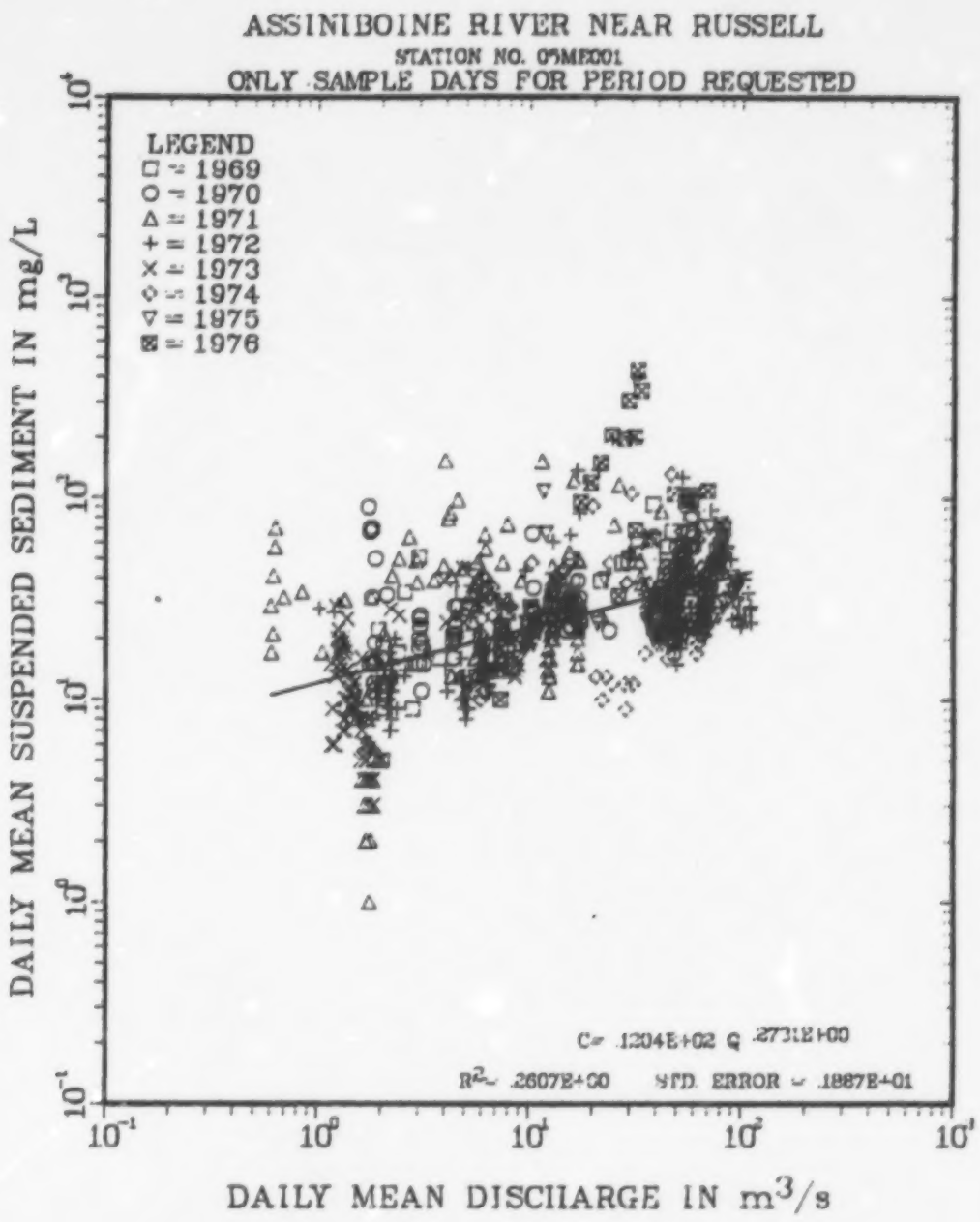


Figure 20 Daily Mean Suspended Sediment Concentration versus Daily Mean Discharge: Russell

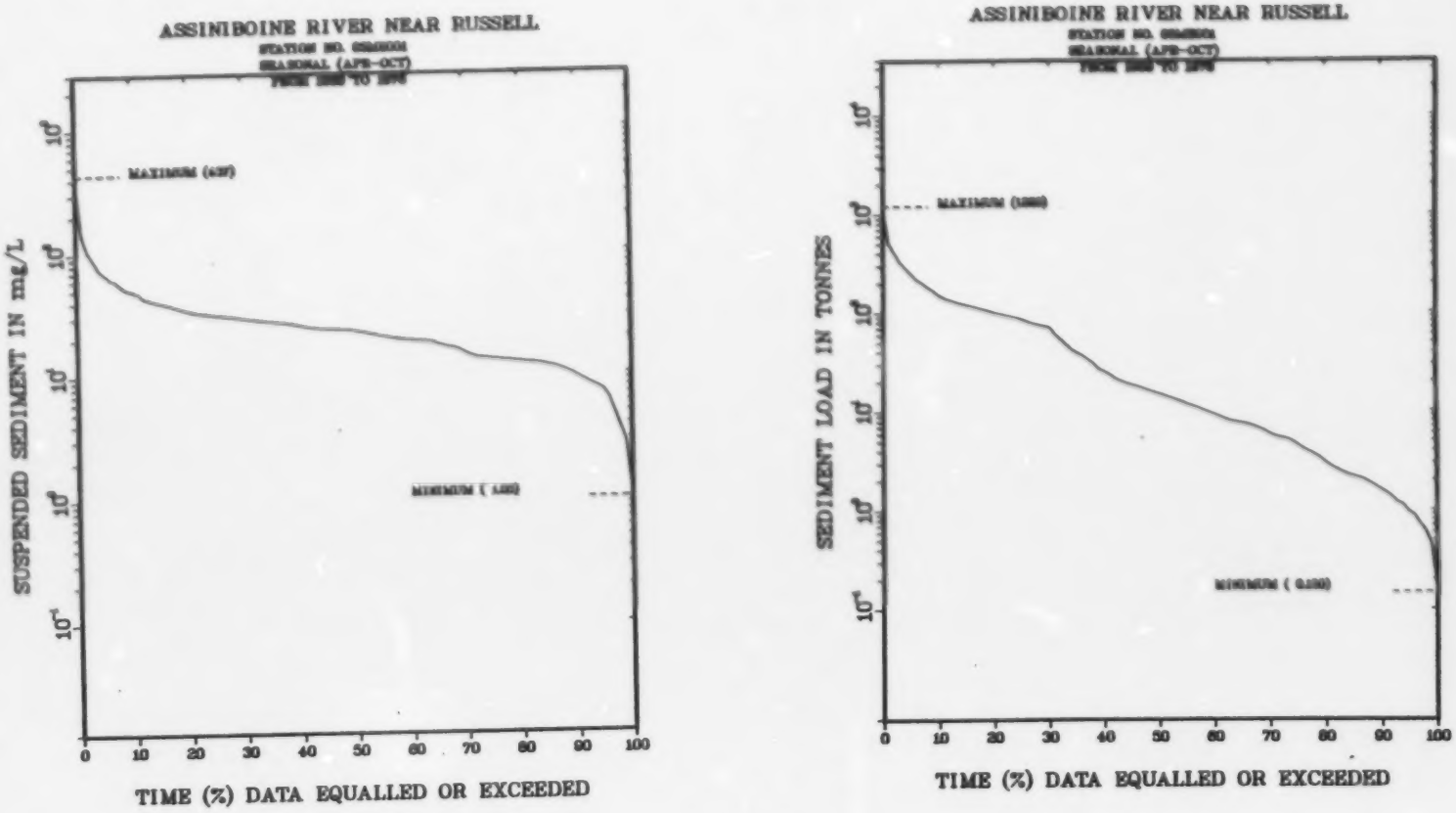

ASSINIBOINE RIVER NEAR RUSSELL
SUSPENDED SEDIMENT IN mg/L
TIME (%) DATA EQUALLED OR EXCEEDED
ASSINIBOINE RIVER NEAR RUSSELL
SEDIMENT LOAD IN TONNES
TIME (%) DATA EQUALLED OR EXCEEDED

Figure 21 Daily Concentration and Load Duration Curves: Russell

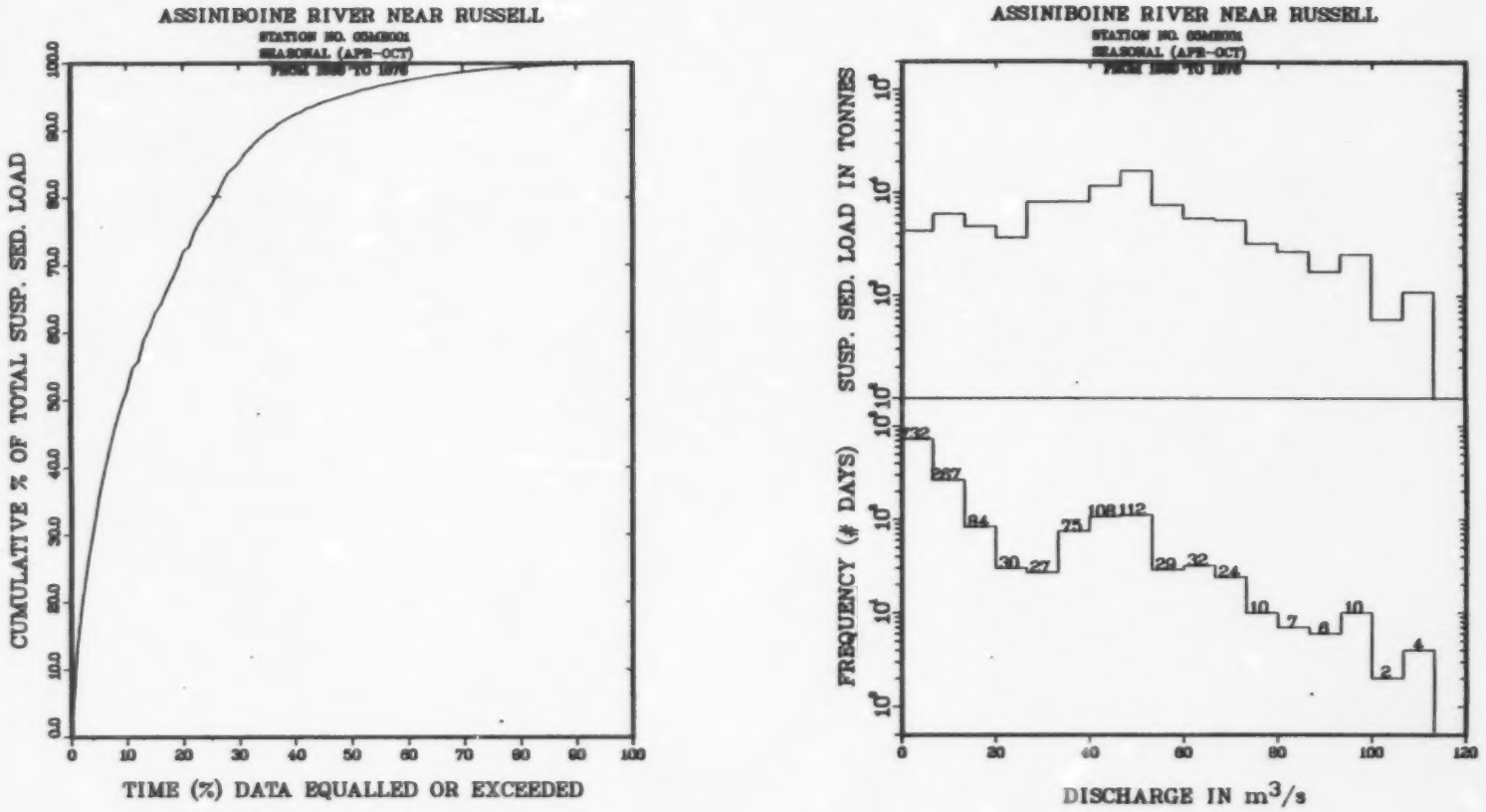


Figure 22 'Effective' Discharge and Cumulative Load Duration Curve: Russell

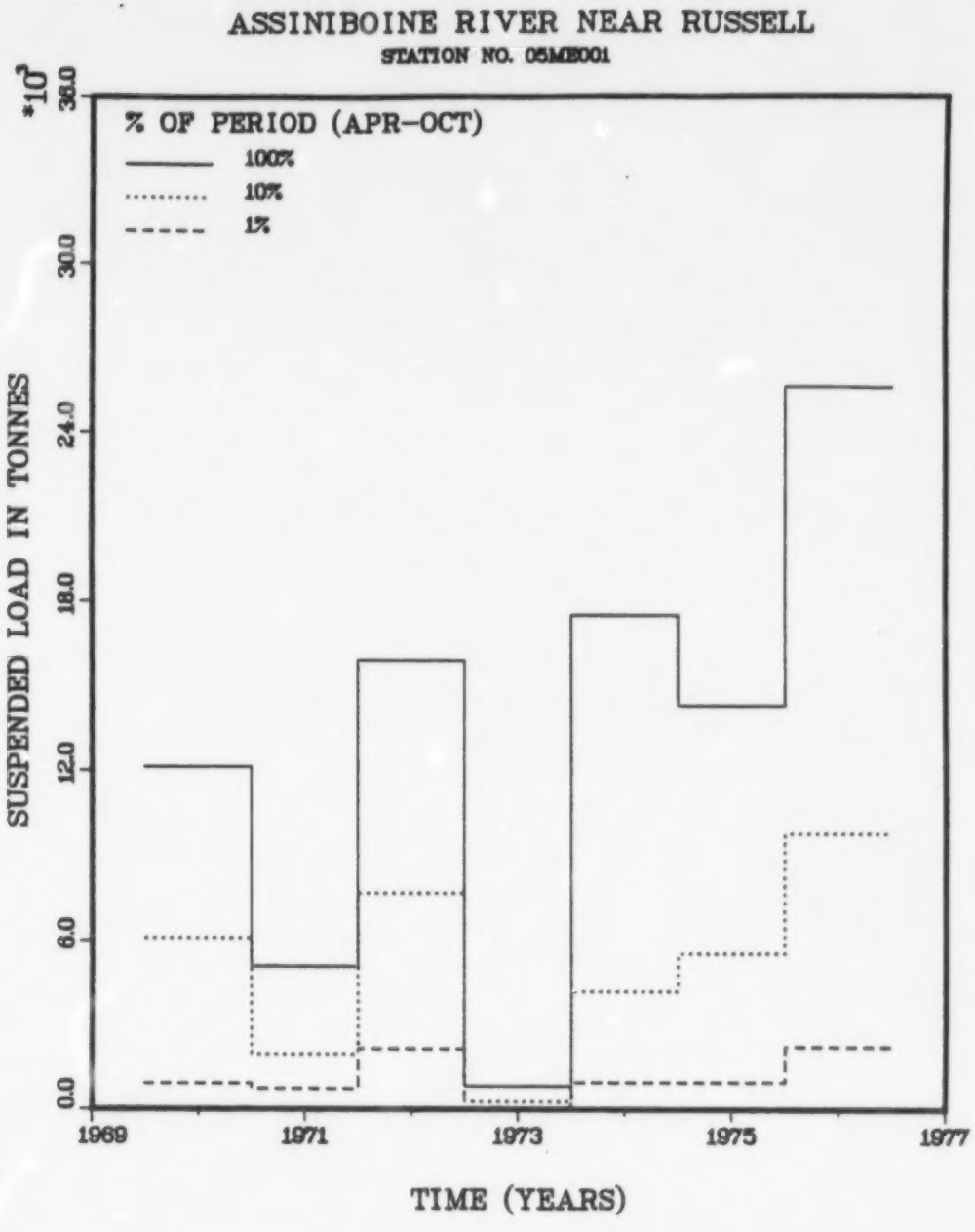


Figure 23 'Best Percent' of the Seasonal Load: Russell

Kamsack, indicating that flow regulation tends to spread the load over a longer time period by eliminating large peak discharges and their large daily loads.

5.6 Total Annual Load and Yield

Mean seasonal load at Russell for the period 1969 to 1976 is 15 700 Mg, with a standard error of the estimate of 22 %. The maximum seasonal load is 29 000 Mg (1976) and the lowest 2 000 Mg (1973). Mean seasonal flow during this period was 328 000 dam^3 giving an average discharge weighted concentration (seasonal load / seasonal flow) of 48 mg l^{-1}.

6. ASSINIBOINE RIVER NEAR HOLLAND (05MH005)

6.1 Station Description and Sediment Program

The sediment station near Holland was established in 1970 primarily to monitor sediment loads into Portage Reservoir (Yuzyk and Penner, 1988). It is also considered a useful station for long-term monitoring of the sediment regime of the river upstream of Portage la Prairie. The present station, with a cableway, was established at the old ferry crossing 1 km downstream of Hwy 34 north of Holland, in 1984. This is about 500 m downstream of the apex of a meander bend. Prior to this, measurements were made from the highway bridge. The station was established as a seasonal hydrometric site in 1961 and a continuous hydrometric station in 1968, shortly before the sediment program began. Flow in the Assiniboine River near Holland is influenced by flow regulation upstream, notably by flood contol at Shellmouth Dam and by regulation of the Qu'Appelle River and Souris River, which both join the Assiniboine between Russell and Holland. The sediment station profile mentions no serious problems with the current operation of this station.

In this portion of the basin the Assiniboine river flows in a series of incised (ingrown) meanders through the Assiniboine Delta. The station is located on the downstream limb of one of these bends, and immediately upstream of a small vegetated island. Similar small bars and islands, as well as numerous submerged bars or dunes, occur elsewhere throughout this portion of the river's course.

At the hydrometric/sediment station the valley is 75 - 80m deep and the river abuts the valley side in many places, producing steep, high bluffs mainly cut in lacustrine sandy-silt and clay (although till and bedrock are exposed in places). The north wall of the valley is mantled by aeolian sand and stabilized sand dunes are widespread on the surrounding upland (Klassen, 1975). The valley contains extensive terraces, particularly on the inside of meander bends. Some of these terraces are paired and relate to former elevations of Lake Agassiz. The valley in the vicinity of Holland is one location for obvious paired terrace development at 315 to 320 m a.s.l. These terraces are underlain by sandy alluvium of the Assiniboine River (Klassen, 1975). There are also low elevation alluvial surfaces with obvious meander scroll bar development. The lower elevation deposits are mainly sand and gravel overlying till, lacustrine deposits or shale bedrock (Klassen, 1975).

The sediment program near Holland was established initially in 1970 on a seasonal basis, but since 1974 it has been run as a continuous program. It is one of only two currently active sediment stations on the Assiniboine River (the other is at Headingley). During seasonal operation, sampling began in early April in order to sample the spring snowmelt peak, and continued into October. In most years the initial rise in the annual hydrograph was sampled, although occasionally the concentrations on the rising limb are interpolated. In the first year of operation (1970) sampling did not begin until July.

Single depth-integrating samples are taken at midstream and K factors computed from samples at five verticals through the cross-section. Ideally 5 to 10 complete samples (8 depth- integrating and 2 point-integrating) are collected per year. Depth-integrating sampling follows a normal flow-weighted scheme: 1 - 2 samples per day during peak flows, 2 - 3 samples per week during medium flows and 1 sample per week during low flows. Winter samples are collected if discharge exceeds 40 $m^3 s^{-1}$ at the time of visit. In practice, during continuous operation (i.e, since 1974), at least one sample per month has been collected during the winter, regardless of the discharge. In 1987 no samples were collected in December, January and February. A total of 1 605 depth-integrating samples have been collected and the flow-weighted sampling scheme has resulted in 977 (61%) of these being collected during flows equalled or exceeded less than 30% of the time (1969-1987) (Fig. 24).

In addition to routine depth-integrating and point-integrating suspended sediment programs, the Holland station also has particle size data for both suspended sediment and bed material, although bed material sampling was discontinued in 1981.

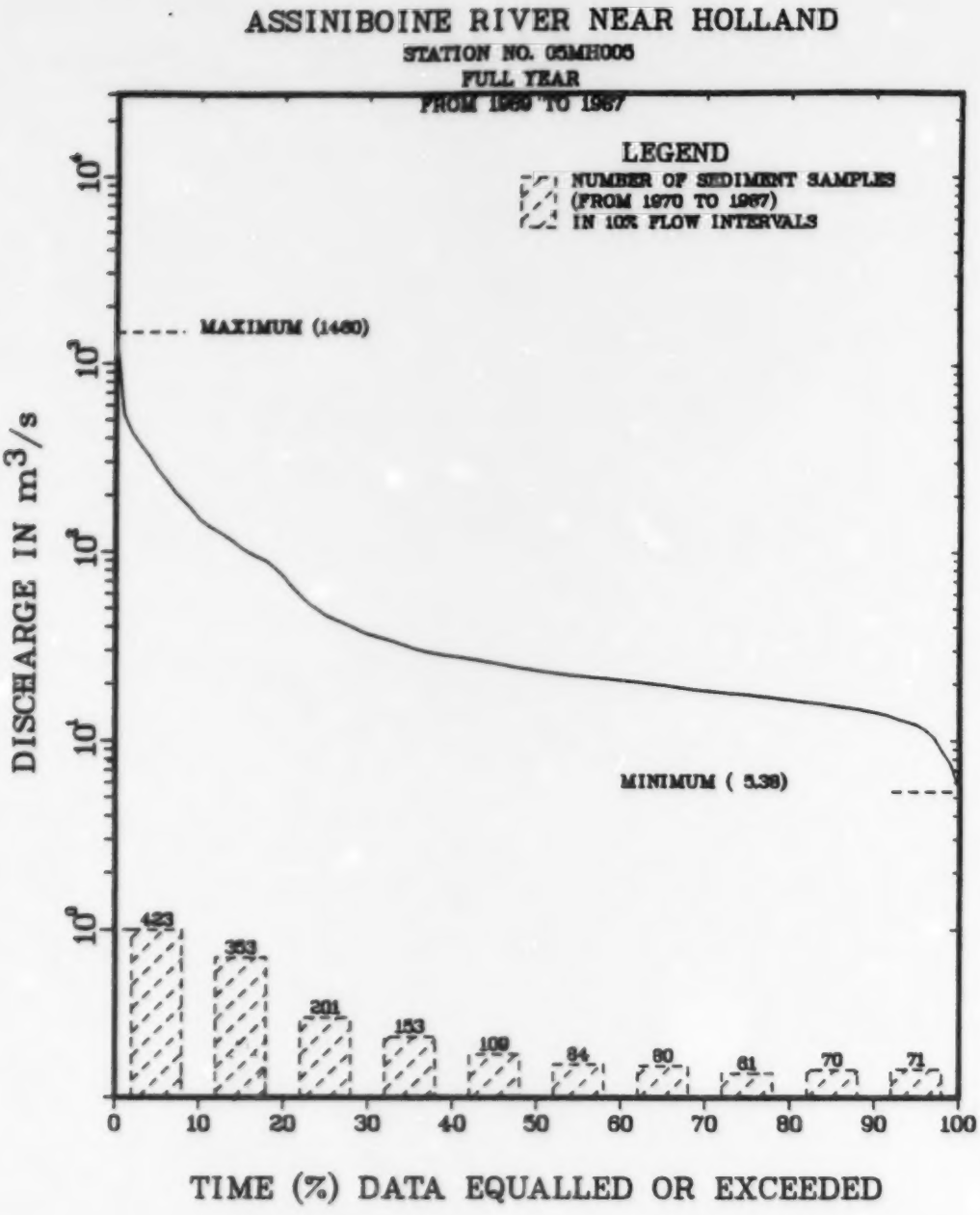


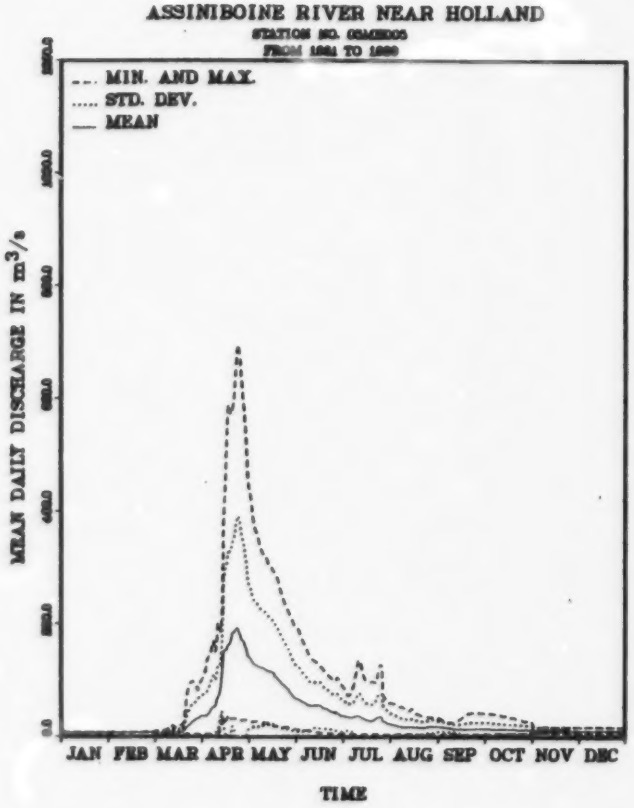
Figure 24 Frequency of Sediment Sampling: Holland

6.2 Flow Coverage

Sampling has covered all the flood peaks since the program began in 1970, except the April peak of 1970. Because the hydrometric record extends back only to 1961, and both the largest and smallest recorded annual maximum and annual total discharges have occurred since 1970, it seems inevitable that sediment sampling has covered adequately the known discharge range in the river. The largest annual maximum daily discharge occurred in 1976 (1 460 $m^3 s^{-1}$ and had a mean daily concentration of 489 mg l^{-1}) and the lowest in 1981 (41.8 $m^3 s^{-1}$). The lowest sampled discharge is 6.48 $m^3 s^{-1}$ in August, 1981 - the minimum recorded discharge since 1969 is 5.48 $m^3 s^{-1}$.

6.3 Annual Discharge and Sediment Regime

The annual mean discharge near Holland is 62.2 $m^3 s^{-1}$ (1968-1976). The annual regime of the Assiniboine River near Holland prior to and since construction of the Shellmouth Dam is shown in Figure 25. The pre-construction regime shows the usual mid to late April snowmelt peak and gradual decline through the summer. Superficially the regime has altered little as a result of the Shellmouth Dam. Prairie Provinces Water Board (1982) computed natural and present use flows for the Assiniboine River at Brandon which show little change in the timing of the spring peak, but reductions of 25% in its magnitude, and augmentation of the winter flows by a factor of two or three. Presumably, the effect at Holland is similar, although modified by the discharge of the Souris River. Reductions in mean discharge are slight.


ASSINIBOINE RIVER NEAR HOLLAND
--- MIN. AND MAX.
..... STD. DEV.
___ MEAN
MEAN DAILY DISCHARGE IN m3/s
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME

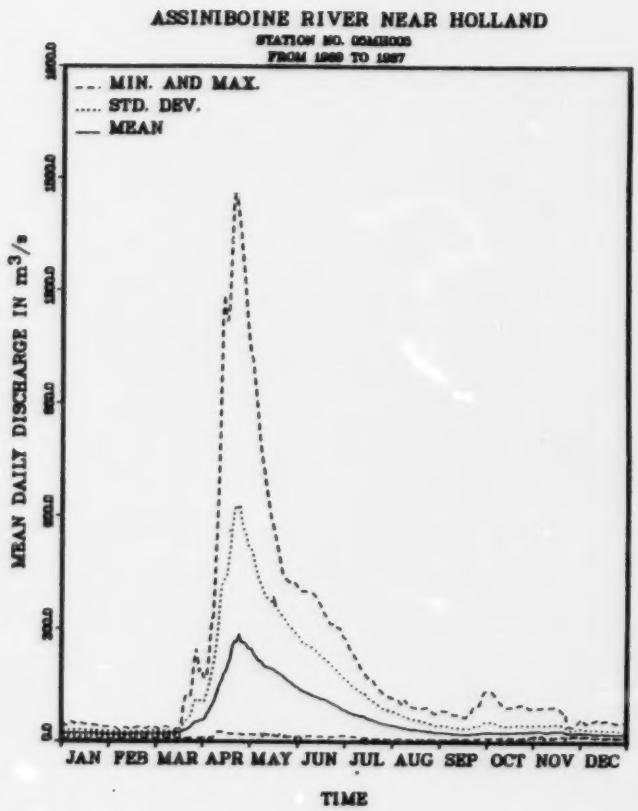
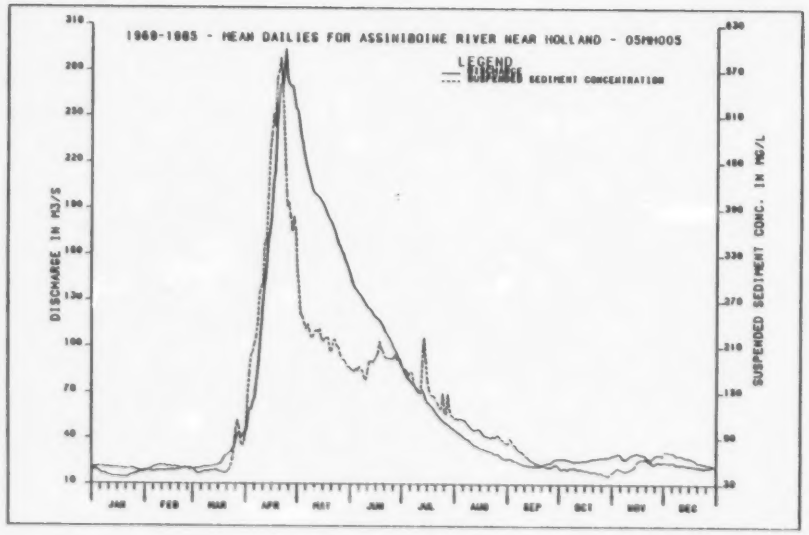
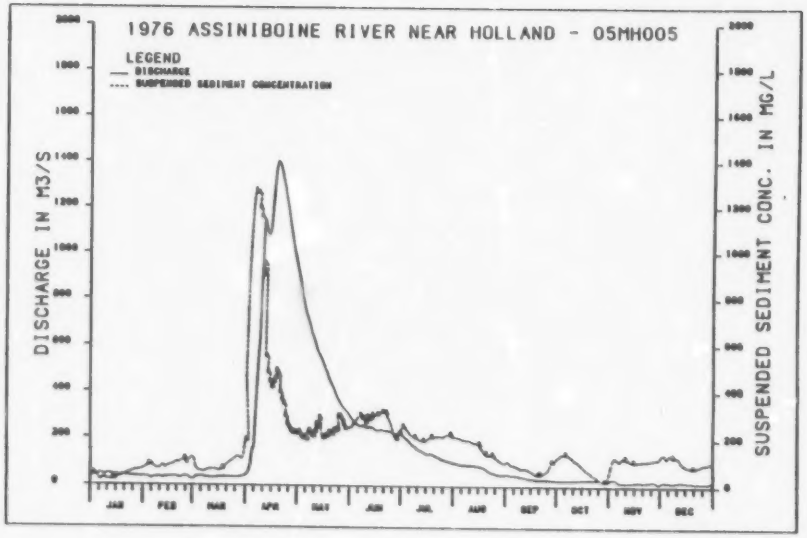

ASSINIBOINE RIVER NEAR HOLLAND
--- MIN. AND MAX.
..... STD. DEV.
___ MEAN
MEAN DAILY DISCHARGE IN m3/s
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME

Figure 25 Annual Hydrograph: Holland

Figure 26 shows examples of the present annual discharge and sediment regime at Holland, along with the graph of average flow and sediment regime, for the period of sediment record (1969-1986). Peak discharge occurs consistently in late April or early May and ranges from 54 to over 1 400 $m^3 s^{-1}$. Only in years of exceptionally low flow (1973, 1977, 1981) has peak discharge occurred at a time other than late April or early May. Winter flows are higher than would be expected under natural flow conditions and generally range from 10 to 20 $m^3 s^{-1}$. In normal years flow declines after the initial peak, although there is often a secondary peak or plateau in the discharge regime, presumably resulting from reservoir drawdown (e.g. 1979, 1986).

The sediment regime follows that of discharge fairly closely. Thus, in normal years, sediment concentration peaks during the spring flood and declines rapidly thereafter. In some cases the sediment concentration peak actually precedes the discharge peak. The falling limb of the annual hydrograph usually shows much lower concentrations than the rising limb. Reservoir releases, with fairly low sediment concentrations, may be partially responsible for this. Winter concentrations are consistently low, but nevertheless are often between 50 and 100 mg l^{-1}. During low flow years the pattern of variation of suspended sediment concentration is much more erratic than this.





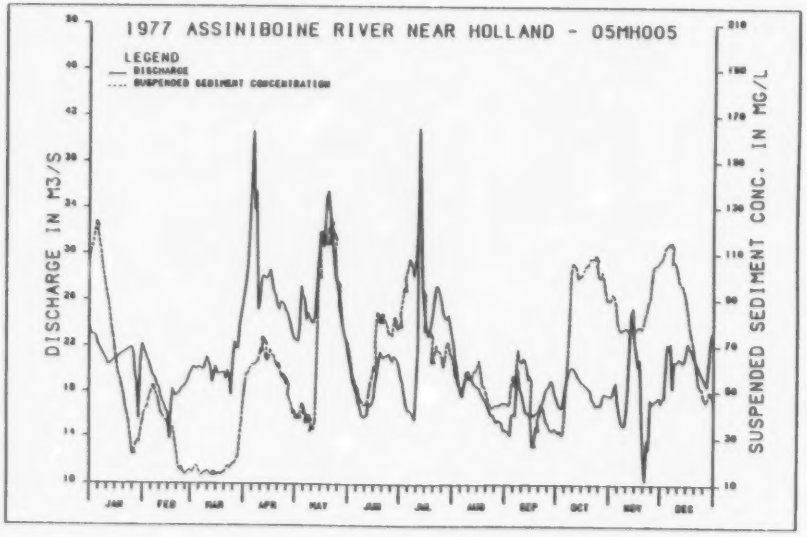
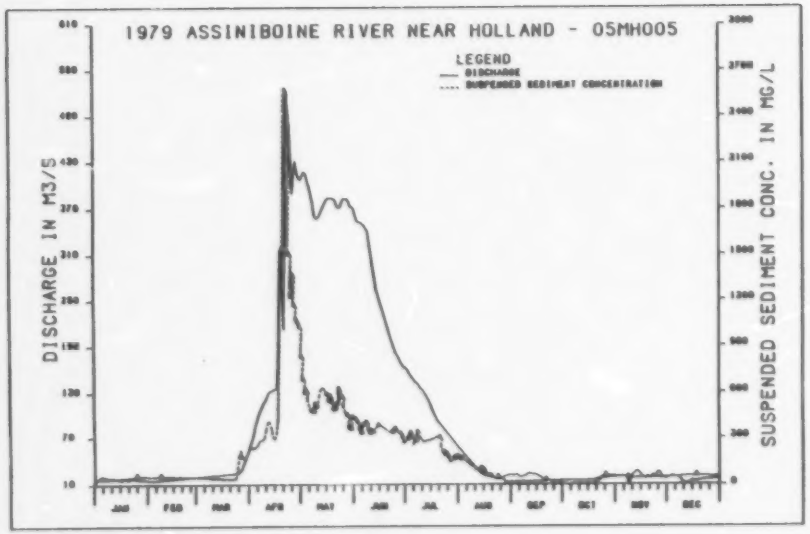
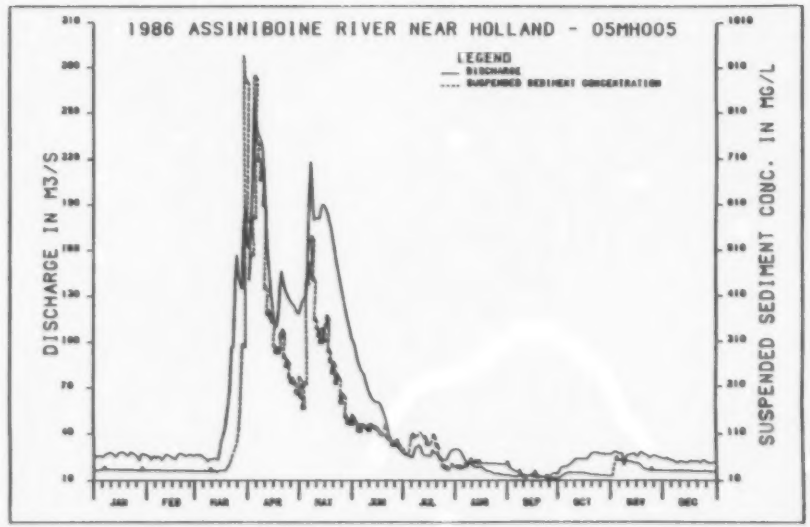


Figure 26 Examples of Annual Hydrographs and Sediment Regimes: Holland





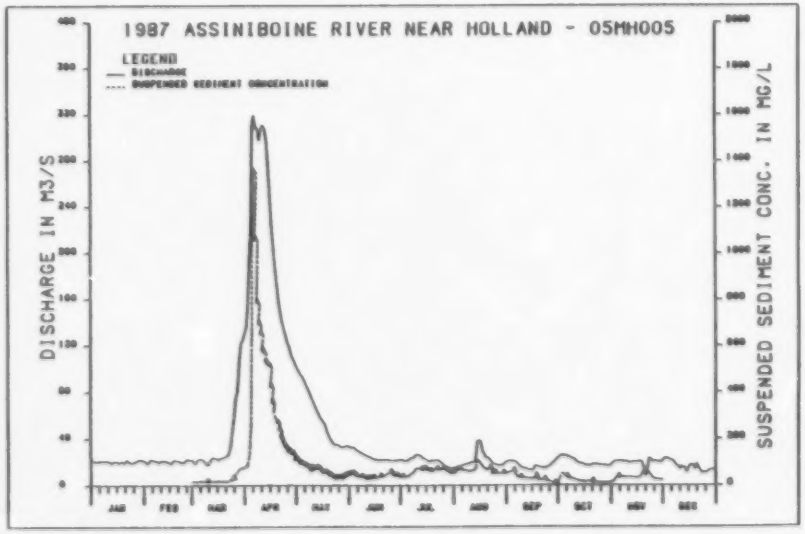


Figure 26 Continued

The general pattern of hysteresis in the relationship between sediment concentration and load is clockwise, at least during the peak flow months (Figure 27). This occurs because of the common tendency for concentrations to be higher on the rising limb than the falling limb of the spring flood. In any given year, of course, this precise pattern may not be followed.

6.4 Daily Mean Suspended Sediment Concentration

The correlation between daily mean concentration and daily mean discharge is quite consistent. R^2 ranges from 0.11 to 0.92 but is generally in the range 0.6 to 0.9 for each annual rating curve. These plots also show the hysteresis effects discussed above. As is typical for these relationships, the concentration at a given discharge scatters over at least an order of magnitude around the best fit ordinary least squares regression (Figure 28).

6.5 Suspended Sediment Concentration and Load

Figure 29 shows the duration curves for daily mean concentration and daily load for the period of continuous sampling from 1975 to 1987 at Holland. Maximum and minimum sampled concentrations are 2 670 and 6.00 mg l^{-1} respectively. Concentrations of 100 and 300 mg l^{-1} are equalled or exceeded 32% and 8% of the time respectively. Median daily mean concentration is 63.2 mg l^{-1}. The maximum and

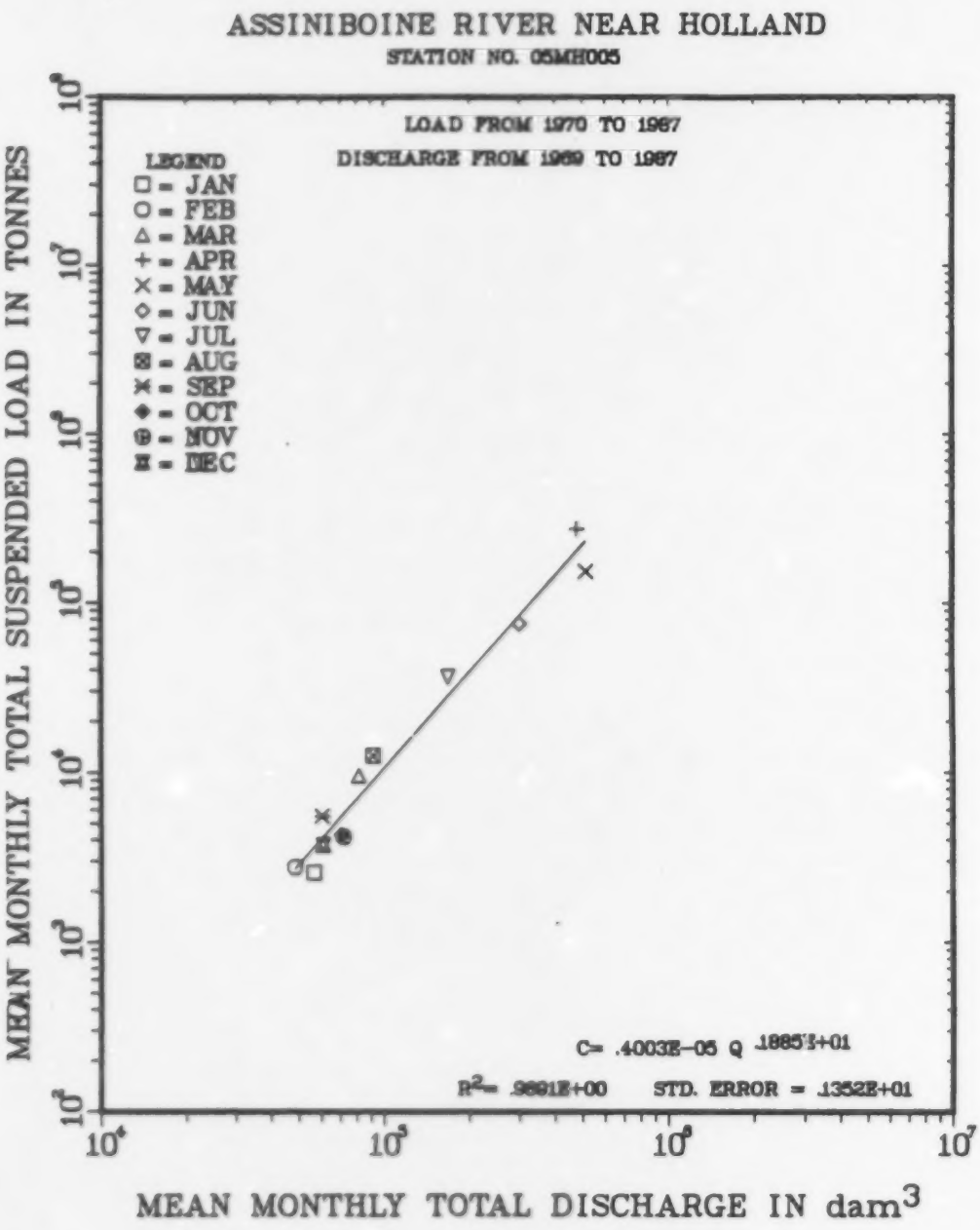


Figure 27 Mean Monthly Total Load versus Mean Monthly Discharge: Holland

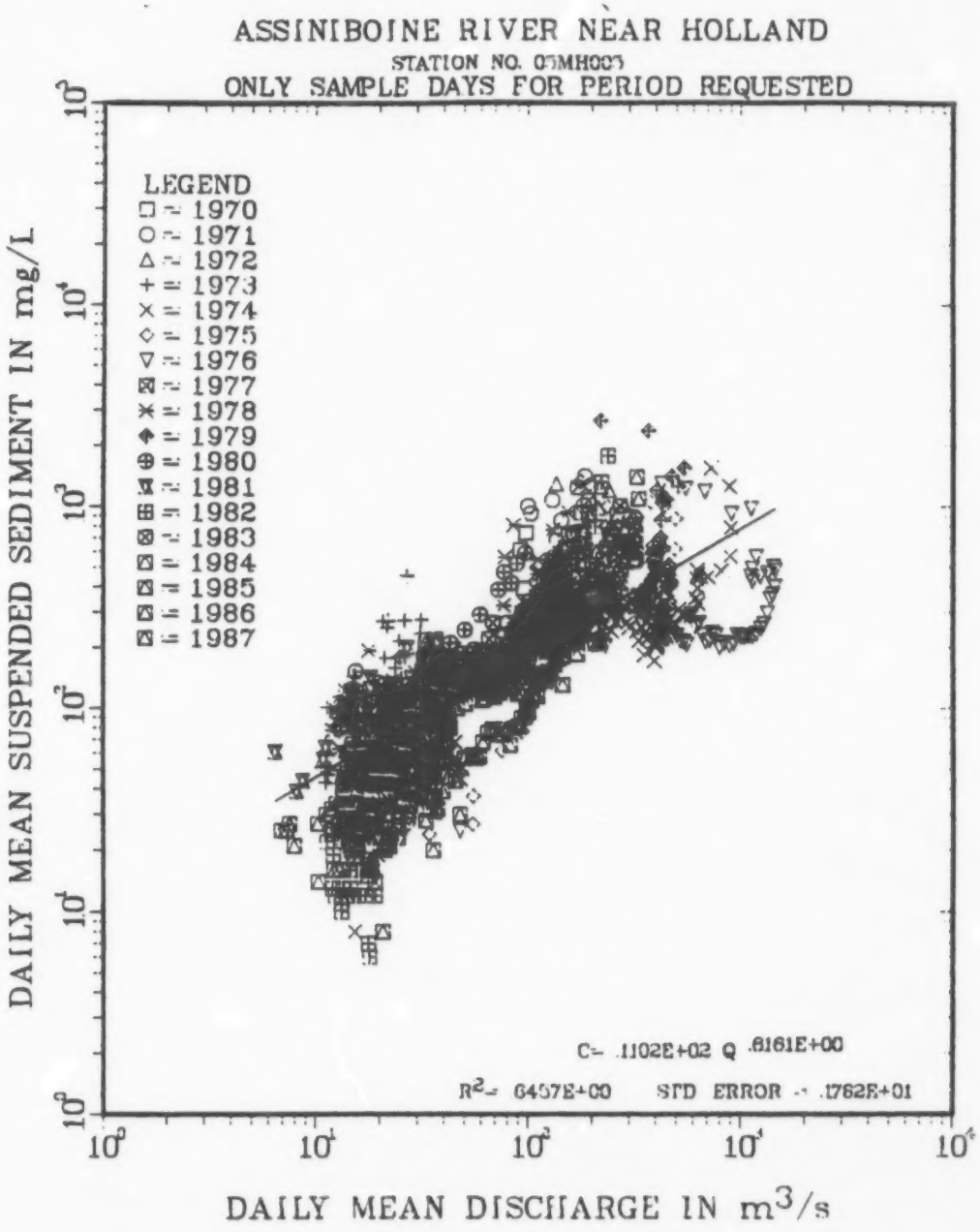


Figure 28 Daily Mean Concentration versus Daily Mean Discharge: Holland

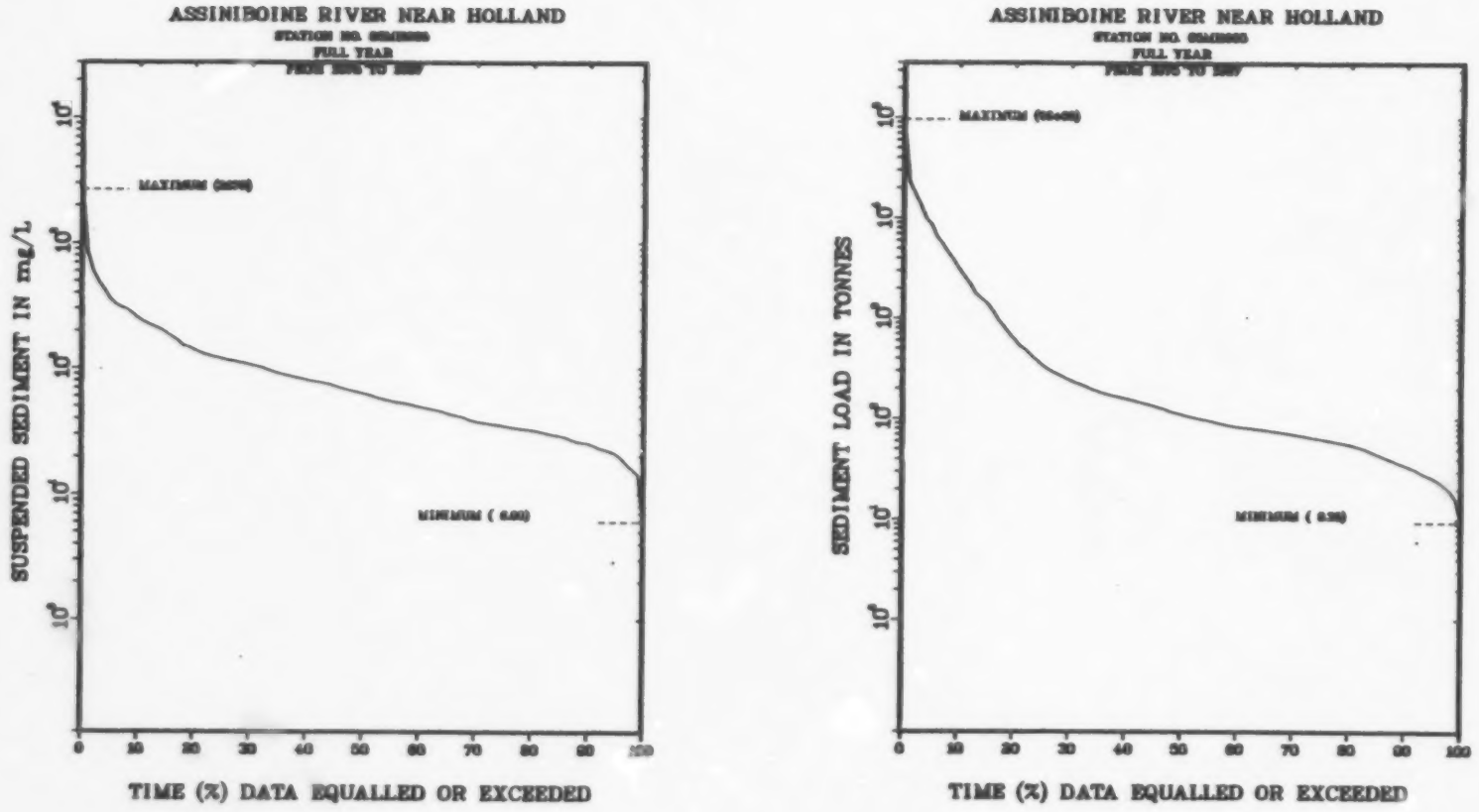

ASSINIBOINE RIVER NEAR HOLLAND
FULL YEAR
SUSPENDED SEDIMENT IN mg/L
TIME (%) DATA EQUALLED OR EXCEEDED
ASSINIBOINE RIVER NEAR HOLLAND
FULL YEAR
SEDIMENT LOAD IN TONNES
TIME (%) DATA EQUALLED OR EXCEEDED

Figure 29 Daily Concentration and Load Duration Curves: Holland

minimum sampled daily loads are 98 800 Mg and 9.38 Mg, and the median is 112 Mg. Daily loads of 1 000 Mg are equalled or exceeded approximately 17% of the time.

Between 1975 and 1987, 80% of the annual load was carried in only 8% of the time (Fig. 30). The 'effective' discharge for suspended sediment transport is 130 - 200 $m^3 s^{-1}$, which has an annual percentage exceedance of 7 - 12% (Fig. 30). The importance of flood events in transporting sediment is apparent from the fact that on the average 37 day (10% of the year) and 4 day (1% of the year) loads are 53% and 15%, respectively, of the annual load (Fig. 31).

6.6 Total Annual Sediment Load and Yield

The mean annual load of the Assiniboine River at Holland from 1975 to 1986 is 597 200 Mg, with a standard deviation of 696 000 Mg, and standard error of the estimate of 35.2%. The seasonal data are not sufficiently complete to compute reliable seasonal loads, except in 1972, 1974 and 1987 which recorded seasonal (April to October) loads of 699 000, 1 300 000 Mg and 299 635 Mg respectively. The April - October load averages 97 % of the annual load and therefore the data for 1972, 1974 and 1987 are good approximations to the annual load for those years.

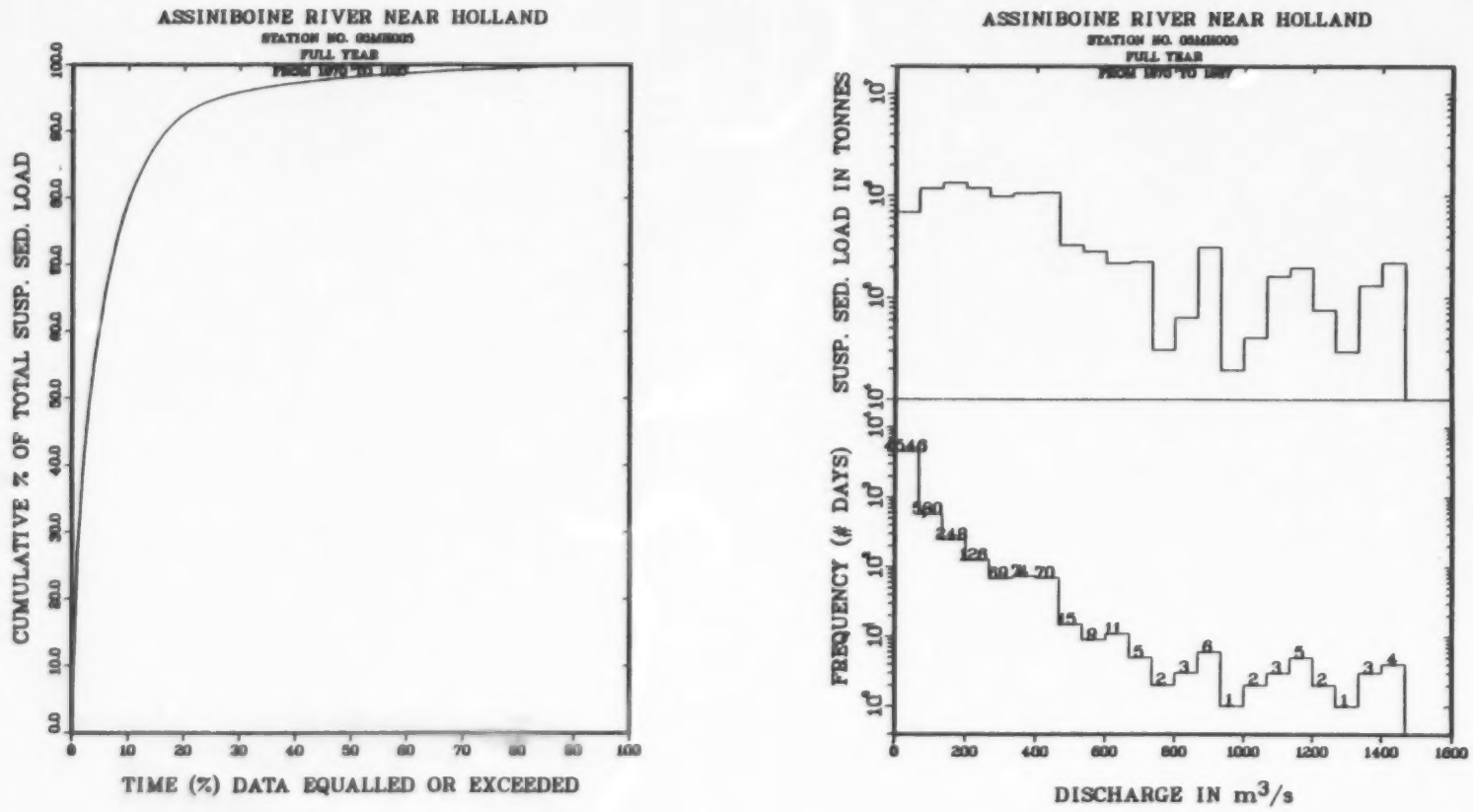

ASSINIBOINE RIVER NEAR HOLLAND
FULL YEAR
CUMULATIVE % OF TOTAL SUSP. SED. LOAD
TIME (%) DATA EQUALLED OR EXCEEDED
ASSINIBOINE RIVER NEAR HOLLAND
FULL YEAR
SUSP. SED. LOAD IN TONNES
FREQUENCY (# DAYS)
DISCHARGE IN m3/s

Figure 30 'Effective' Discharge and Cumulative Load Duration Curves: Holland

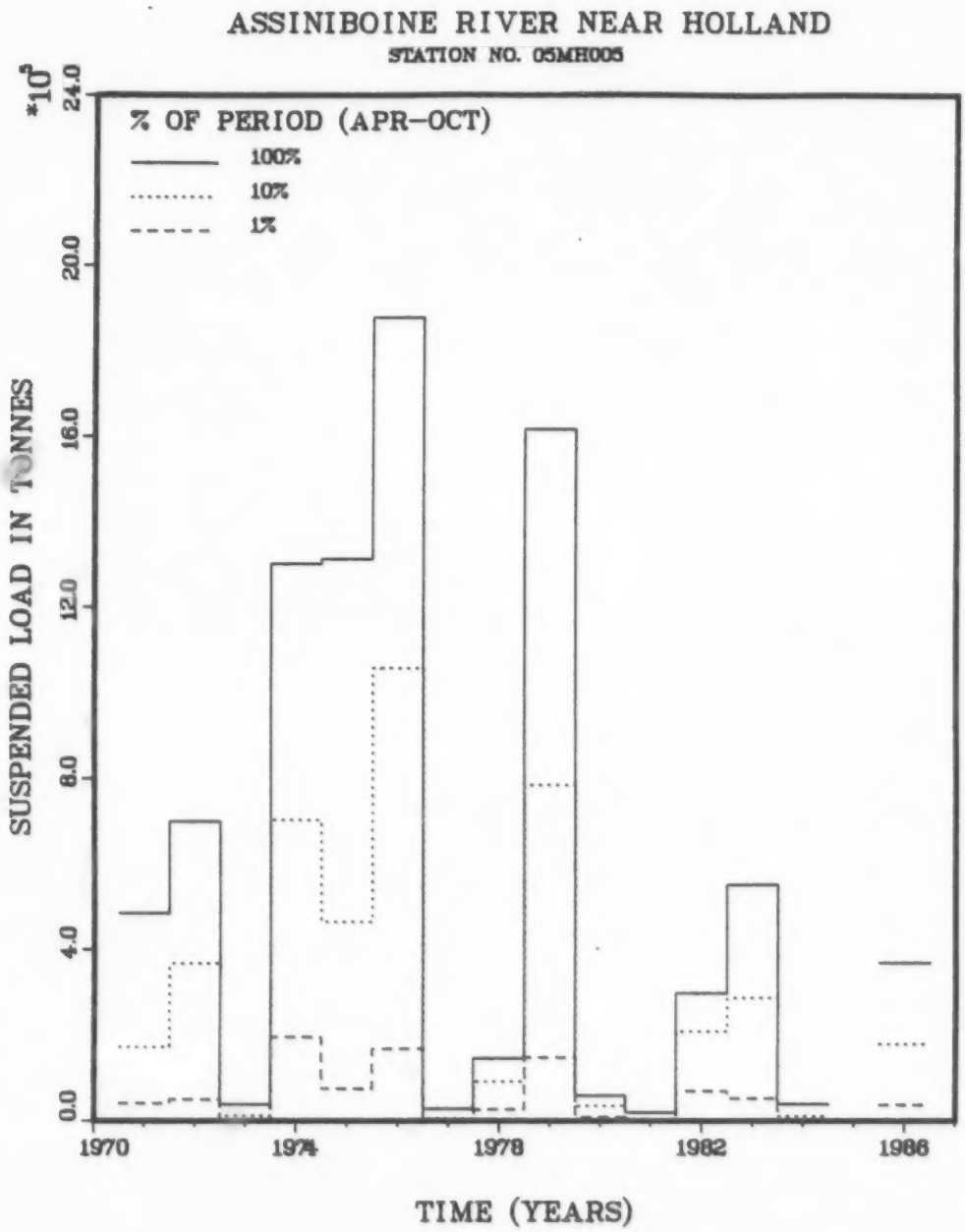


Figure 31 'Best Percent' of the Annual Load: Holland

Annual loads range from 49 500 Mg (1984) to 1 910 000 Mg (1976). The standard error of the estimate of mean annual load is very high and declines only slightly with additional years of record. At present it would require well over 20 years of record to bring the standard error down to 20% (Fig. 32). This highly variable annual load is reflected in the plot of cumulative load against cumulative discharge (Figure 33) in which it is apparent that the three years 1975, 1976 and 1979 transported a disproportionate amount of the cumulative load (approximately 75%) for the period 1975 to 1986. Mean annual total discharge for the period 1975 to 1986 was 1 857 000 dam ^{3}, giving an average annual load / annual discharge ratio of 321 mg l^{-1}.

6.7 Bed Material Particle Size

Figure 34 shows the particle size distribution curves for bed material samples from the Assiniboine River near Holland collected between 1973 and 1981. The majority of samples (12 of 19) were collected at low flow with a BMH-53 sampler. The remainder were collected with the BM-54. Each sample is compounded from 4 or 5 sub-samples distributed across the cross-section. The mean D_{50} of these samples is 0.685 mm. Removing one outlier reduces this to 0.482 mm. On average, approximately 15% by weight is coarser than 2 mm. Thus, the bed material might be characterized as poorly sorted, coarse sand and gravel. The station notes mention the presence of small boulders in the channel also.

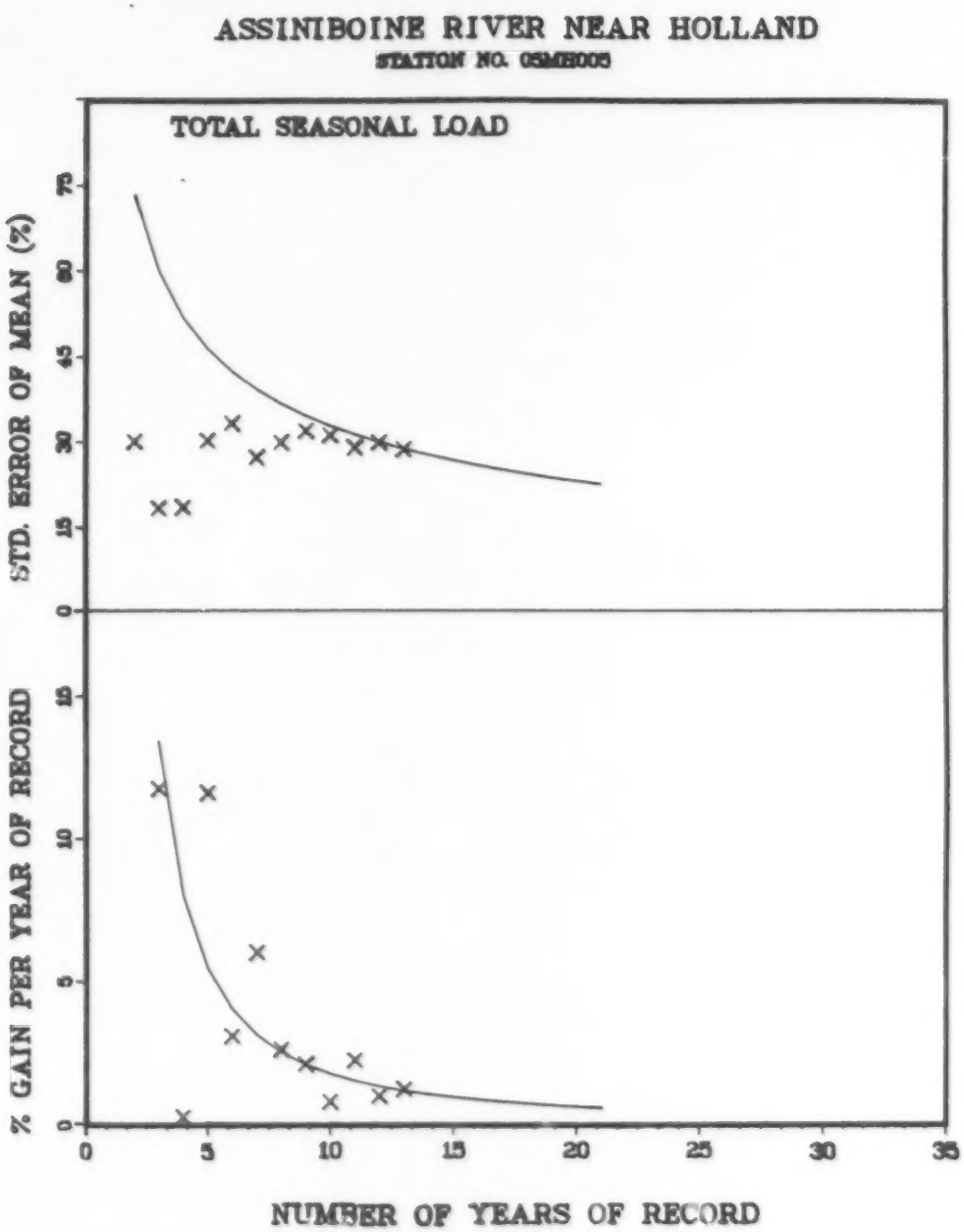


Figure 32 Standard Error of the Annual Load: Holland

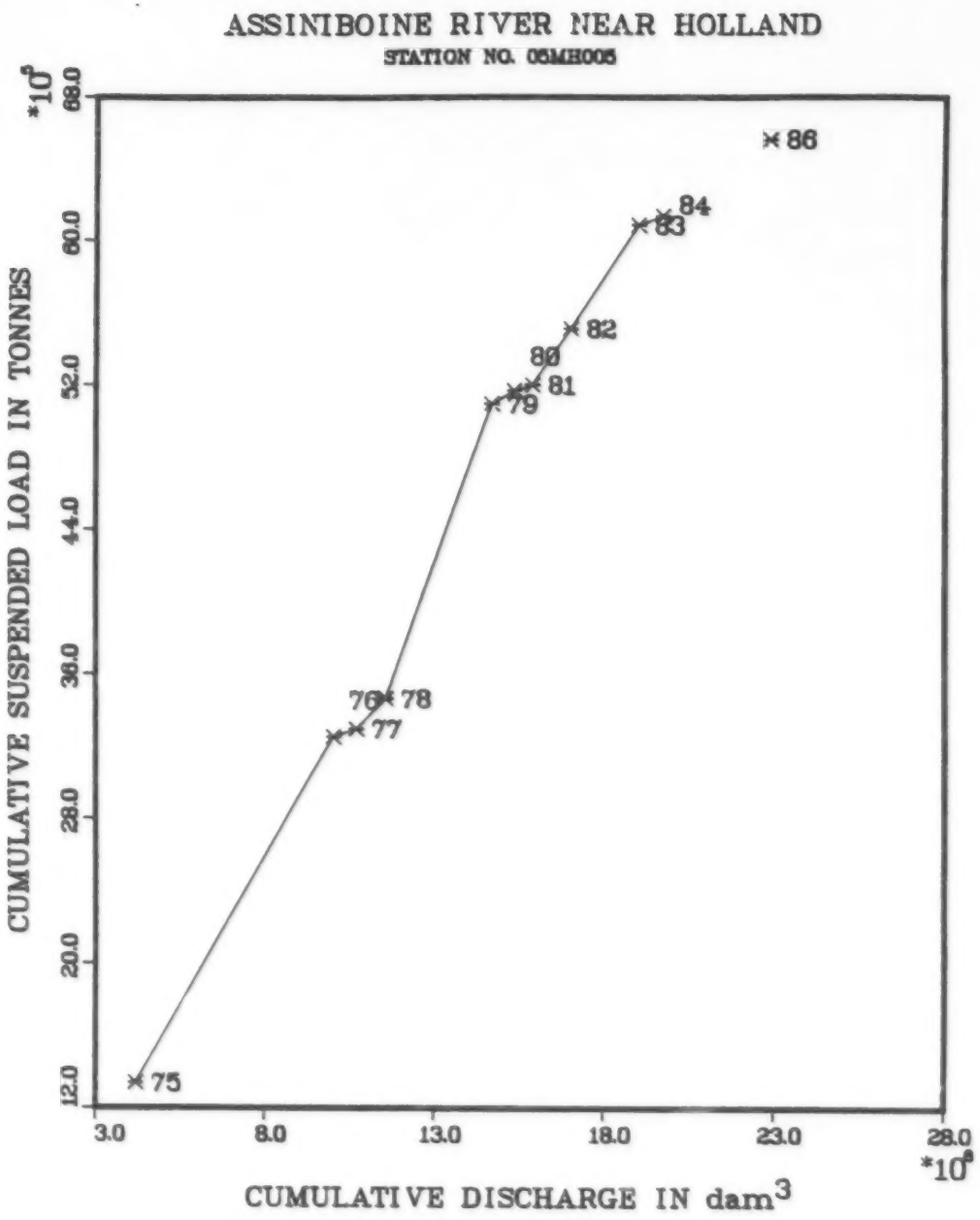


Figure 33 Cumulative Load versus Cumulative Discharge: Holland

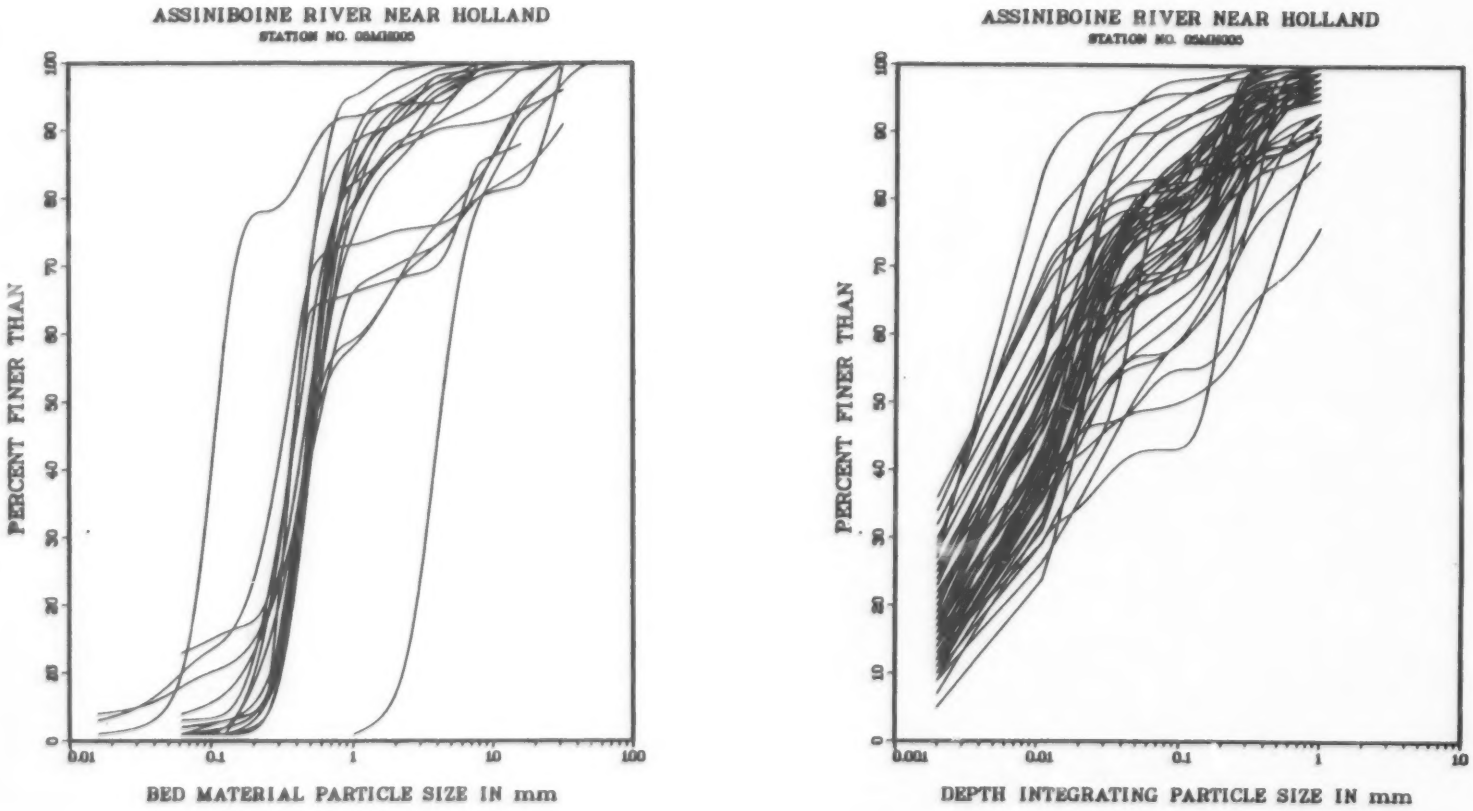

ASSINIBOINE RIVER NEAR HOLLAND
STATION NO. 05MM005
PERCENT FINER THAN
BED MATERIAL PARTICLE SIZE IN mm
ASSINIBOINE RIVER NEAR HOLLAND
STATION NO. 05MM005
PERCENT FINER THAN
DEPTH INTEGRATING PARTICLE SIZE IN mm

Figure 34 Bed Material and Suspended Sediment Particle Size Distributions: Holland

6.8 Suspended Sediment Particle Size

To date there are 56 particle size analyses of depth- integrating samples collected at concentrations ranging from 288 to 2 890 mg l^{-1} and daily mean discharges between 86 and 1 470 $m^3 s^{-1}$. The suspended sediment particle size is highly variable (Fig. 34). D_{50} ranges from 0.0052 to 0.152 mm and percentage sand ranges from 4 to 51%, and percent clay from 9 to 43%. There is an obvious increase in percent sand and D_{50} of the sand fraction with increasing discharge (Figure 35), suggesting that there is a considerable bed material contribution to the suspended load at high discharge.

6.9 Point-Integrating Samples

There have been two full point-integrating samples at this site; on April 13, 1976 when discharge was 1 250 $m^3 s^{-1}$, and on April 11, 1987 when the discharge was 320 $m^3 s^{-1}$. The sample verticals were at different locations on these two days.

In 1976 the verticals were at 45.7 m, 69.2 m, 88.4 m, 112.8 m and 134.1 m. Mean concentration is highest at verticals 69.2 and 88.4 and lowest at vertical 134.1, where average concentration is about 25% of that near the centre of the section. Most of this decrease is accounted for by the dramatic drop in sand concentration towards the margin of the channel - silt and clay fractions are distributed fairly uniformly across the section. Average concentration at the bed is twice that at the surface and most of this is accounted for by the strong vertical

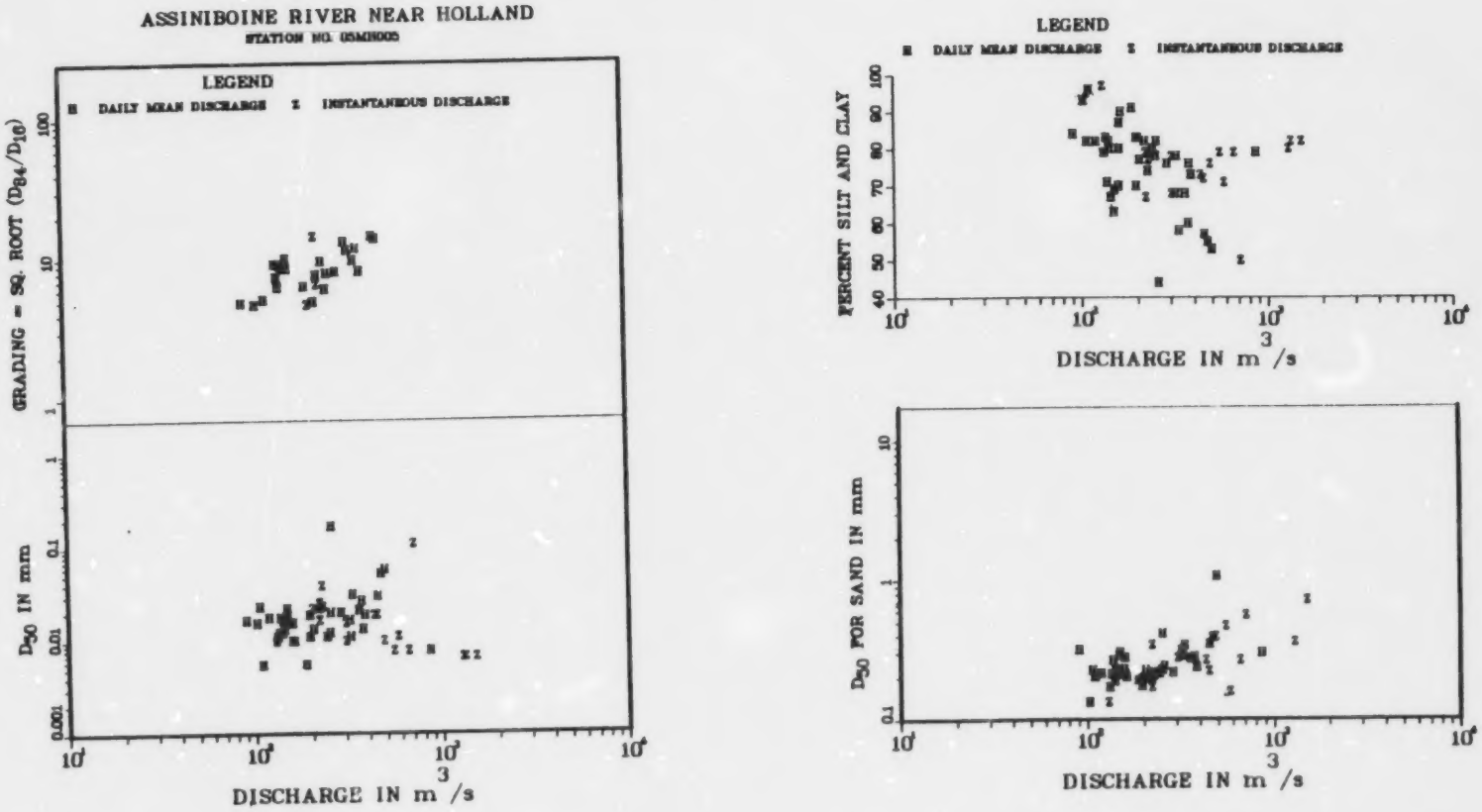


Figure 35 Suspended Sediment Particle Size Characteristics versus Discharge: Holland

concentration gradient for the sand fraction - except at one vertical where the sand concentration is very low, sand concentration near the bed averages 6% of that at the surface. Both silt and clay fractions are distributed almost uniformly in the vertical. The high sand concentrations near the bed are suggestive of a large bed material load at higher discharges, as suggested by the depth-integrating particle size analyses.

The verticals for 1987 are at 24, 40, 56, 72 and 88 metres. The lateral and vertical variation in particle size and concentration is not as pronounced for this sample as for the sample at considerably higher discharge in 1976. Average concentration declines near the channel margin (vertical 24) to about 60% of that at the centre of the channel, largely because of a drop in sand concentration. Silt and clay are distributed almost uniformly in the vertical, while sand concentrations near the surface average 30% of the concentration near the bed.

7. ASSINIBOINE RIVER NEAR ROSSENDALE (05MJ005)

7.1 Station Description and Sediment Program

The sediment station and hydrometric program near Rossendale were established in 1970 to monitor loads to Portage Reservoir. The sediment record overlaps with the station near Holland. The Rossendale station operated on a seasonal or continuous program for three years, and a miscellaneous program for an additional year (1973), before being closed because of hydrometric problems. Thus, there are only three years of sediment data. The proximity of this station to the station near Holland means that the Rossendale data may be combined with those from Holland. The station is located in a curved reach at the Hwy 242 bridge crossing north of Rossendale. The meandering river has incised a valley which is 2 - 3 km wide and 40 - 50 m deep and contains some extensive high floodplain and terrace surfaces. The channel itself contains obvious active sand bars and unvegetated point bars. The flow regime at this site is affected by flow regulation at the Shellmouth Dam and by contributions from the Qu'Appelle and Souris rivers.

Collection of depth-integrating samples began in April, 1970 and extended through to the end of October, 1972. The station continued on a miscellaneous basis through 1973. The data for 1970 and 1972 are seasonal, while those for 1971 cover the whole year. In all years, sampling covered the spring discharge peak. In total there are 335 depth-integrating samples at this station. The sampling scheme has

resulted in approximately 47% of these samples being collected at flows equalled or exceeded less than 30% of the time (Fig. 36). This flow weighting of the samples is less pronounced than at other sediment stations on the Assiniboine River. In addition to the routine depth-integrating sediment concentrations, there are also bed material and suspended sediment particle size data, and 2 full point- integrating measurements, one each in 1970 and 1971.

7.2 Flow Coverage

The period of sediment and flow record at this station is so short that it is difficult to assess the extent to which the sampling scheme has covered the extreme events. The maximum recorded daily discharge is 496 $m^3 s^{-1}$ and the minimum is 13.7 $m^3 s^{-1}$. Sediment samples were collected on both of these days and therefore the existing data cover the complete discharge range for the period 1970 - 1972. However, when compared with the much longer flow record at Holland (there are no significant tributaries between the two and flow records for 1971 and 1972 show that total annual and maximum daily discharge at the two stations are almost identical), these maximum and minimum recorded discharges represent durations of 1-2% and 91% respectively. The maximum recorded daily discharge would have a recurrence interval of about 3 - 5 years at Holland. Thus extreme events are not represented in the record at Rossendale. This is confirmed by the flow record at Holland which shows that

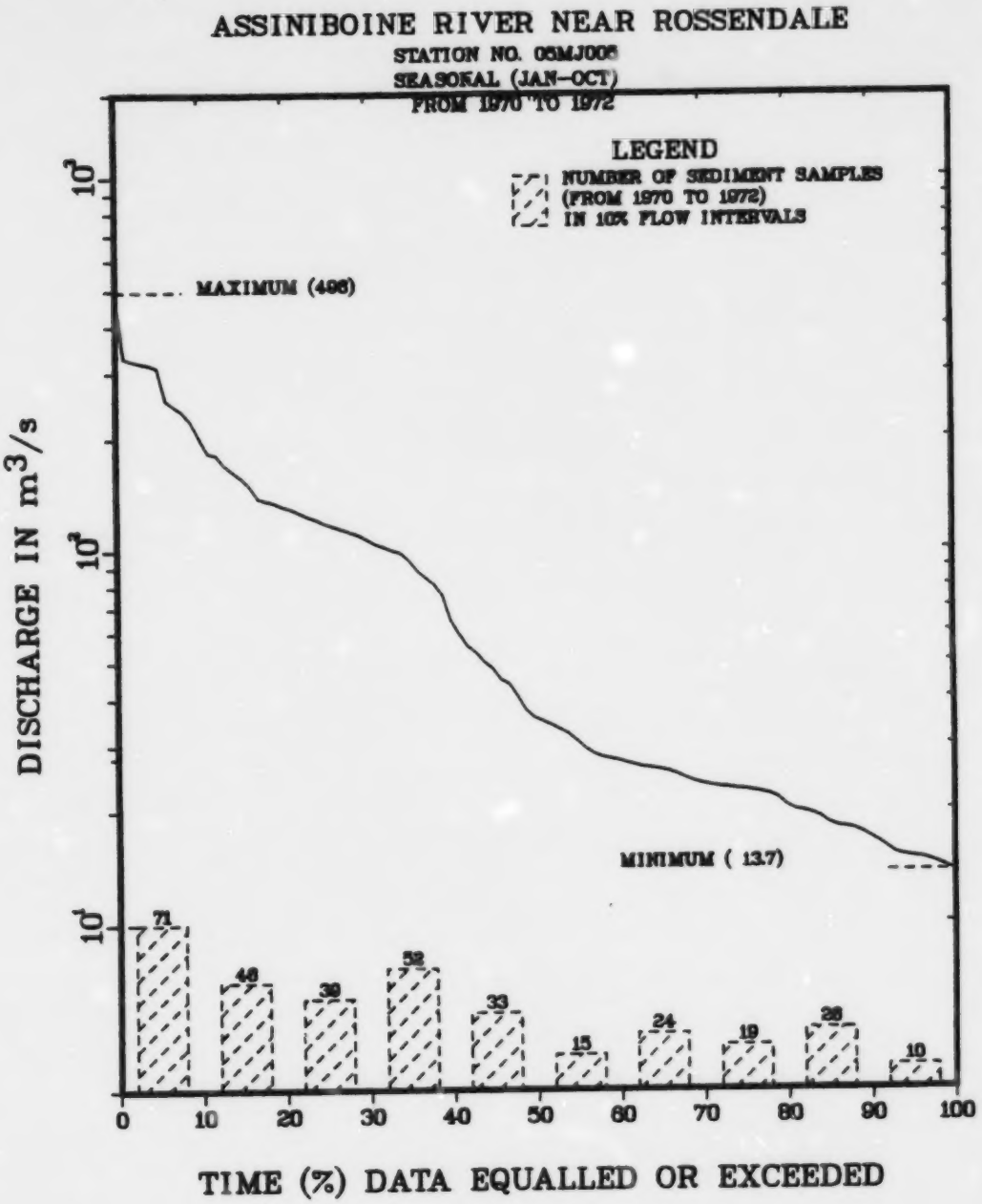


Figure 36 Frequency of Sediment Sampling: Rossendale

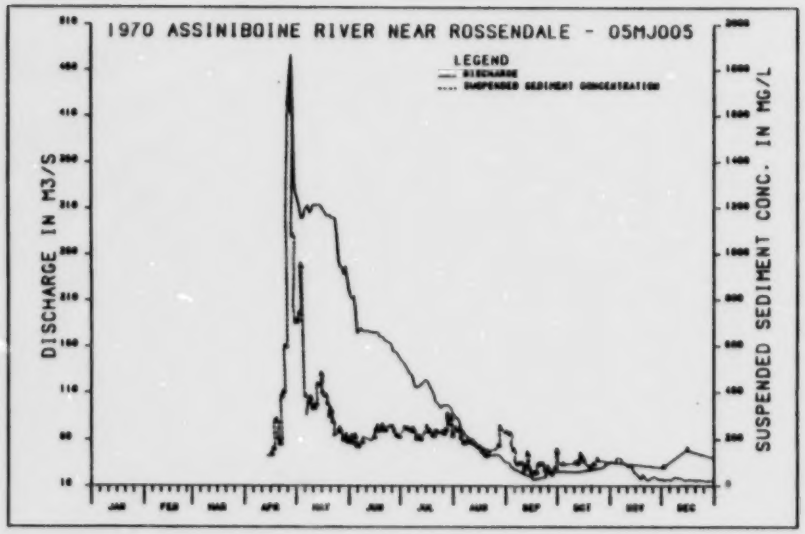
the years 1970, 1971 and 1972 rank 6th, 7th and 10th for total annual flow between 1969 and 1987, and 5th, 9th and 13th for annual maximum flow during the same period.

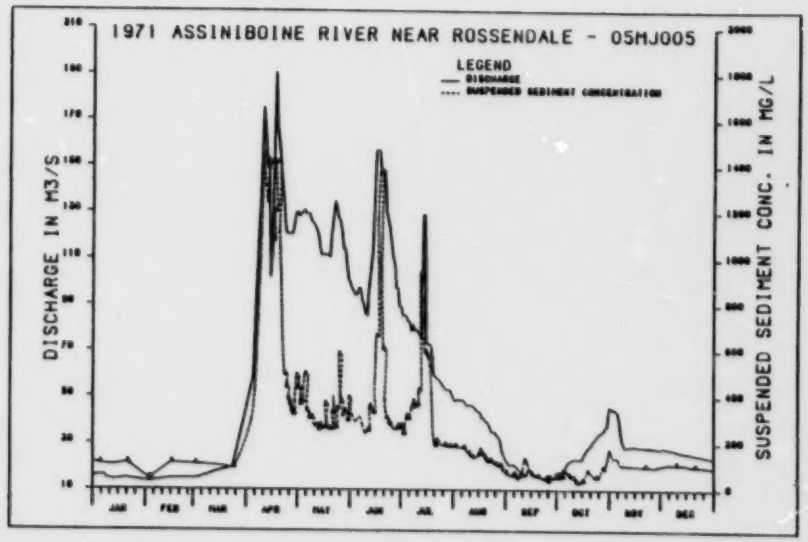
7.3 Annual Discharge and Sediment Regime

Annual mean discharge at Rossendale (for 1971 and 1972 only) is 60.4 $m^3 s^{-1}$. As in the case of the Assiniboine River near Holland, the flow regime near Rossendale is influenced by flow regulation at the Shellmouth Dam. Because there are no major discharge inputs between Holland and Rossendale the flow regime at Rossendale is almost identical to that at Holland (Fig. 37). The discharge peak occurs in mid or late April in all three years 1970-1972, and declines gradually through the summer, modified by reservoir releases. Winter flows are consistently between 10 and 20 $m^3 s^{-1}$. The suspended sediment regime follows the discharge regime; peak concentrations of 1 200 to 1 800 mg l^{-1} coincide with the peak discharge in late April, and then decline rapidly on the falling limb of the annual hydrograph, remaining less than 200 mg l^{-1} during the fall and winter.

7.4 Daily Mean Suspended Sediment Concentration

All three years of record show a strong correlation between daily mean discharge and daily mean suspended sediment concentration. In each year there is an obvious clockwise hysteresis in the relationship during the spring flood event (Fig. 38).





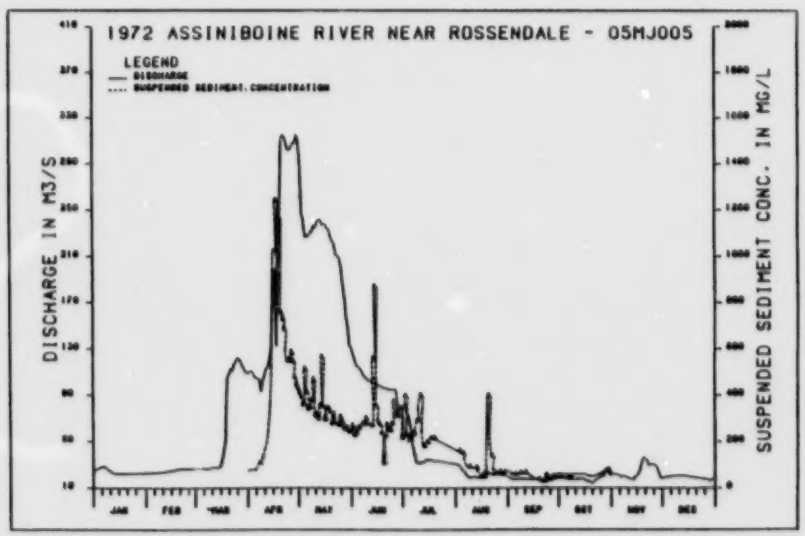


Figure 37 Annual Hydrographs and Sediment Regimes: Rossendale

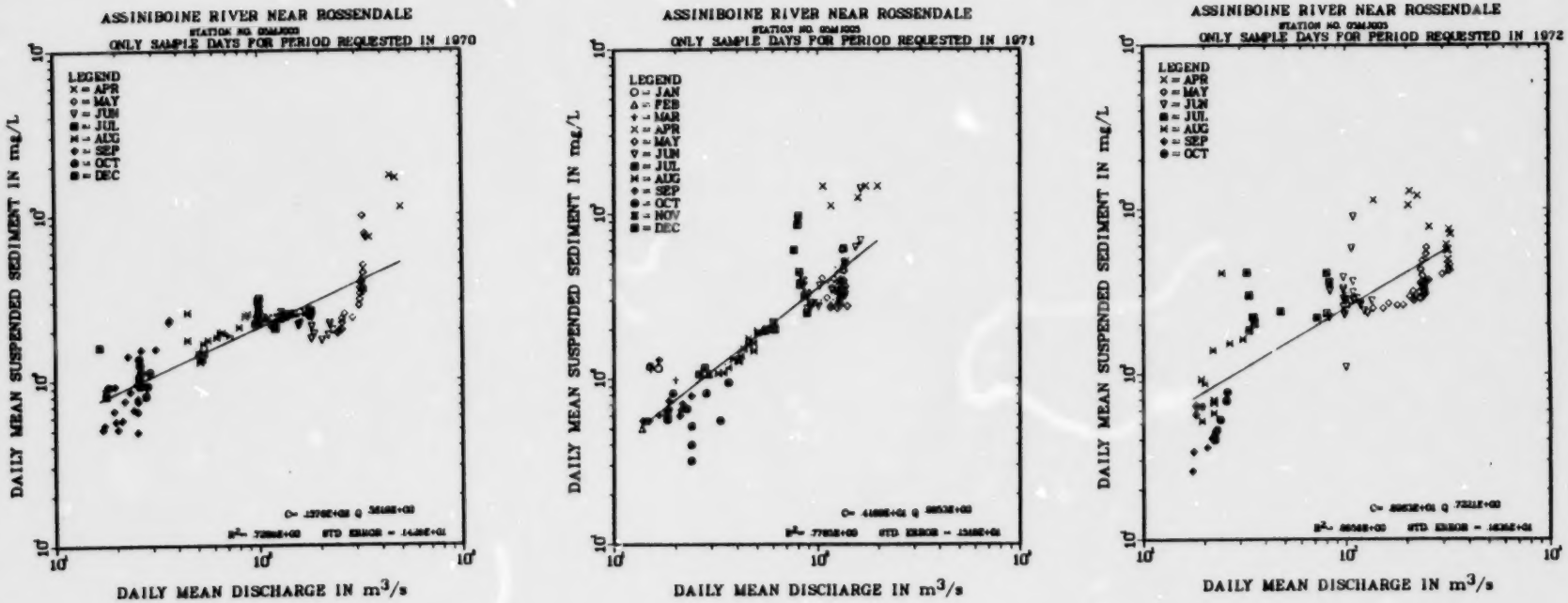


Figure 38 Daily Mean Suspended Sediment Concentration versus Discharge: Rossendale

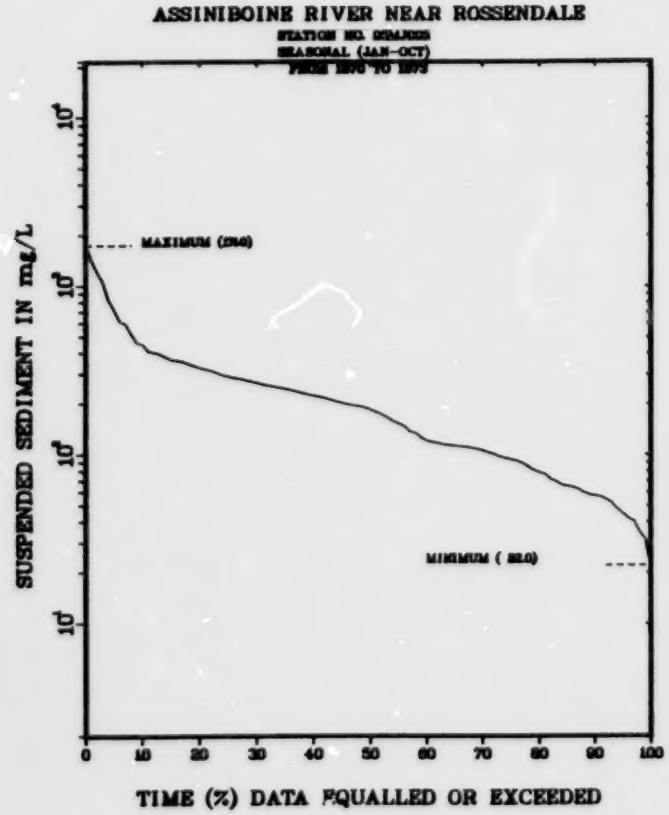
7.5 Suspended Sediment Concentration and Load

Figure 39 shows the duration curves for daily concentration and load near Rossendale (for 1970 to 1972, April - October). Daily concentration for the period of record ranges from 22 to 1,740 mg l^{-1}. The median concentration is 185 mg l^{-1}, and concentrations of 100 and 300 mg l^{-1} are equalled or exceeded 72 % and 24 % of the time respectively. Maximum and minimum daily loads are 67 800 and 38.6 Mg respectively. The median daily load is 714 Mg and daily loads of 1 000 Mg are equalled or exceeded 44 % of the time.

For the years 1971 and 1972, 80 % of the seasonal (April-October) load is carried in 23% of the time. The average load transported during the highest 1% (2 days) and 10% (24 days) of the season are 7% and 45 %, respectively, of the total seasonal load. The 'effective' discharge for suspended sediment transport is 300-330 m^3 s^{-1}, which has an annual exceedance percentage of 1-5%. However, these figures are derived from a very short record and may not be reliable over longer time periods.

7.6 Total Annual Sediment Load and Yield

The total annual load can be computed for 1971 and 1972 only, because sampling in 1970 missed the rise to the spring peak. The mean seasonal (April to October) load is 652 000 Mg with a standard error of the mean of 3.4%. This small standard error arises from the similarity of total loads in 1971 and 1972



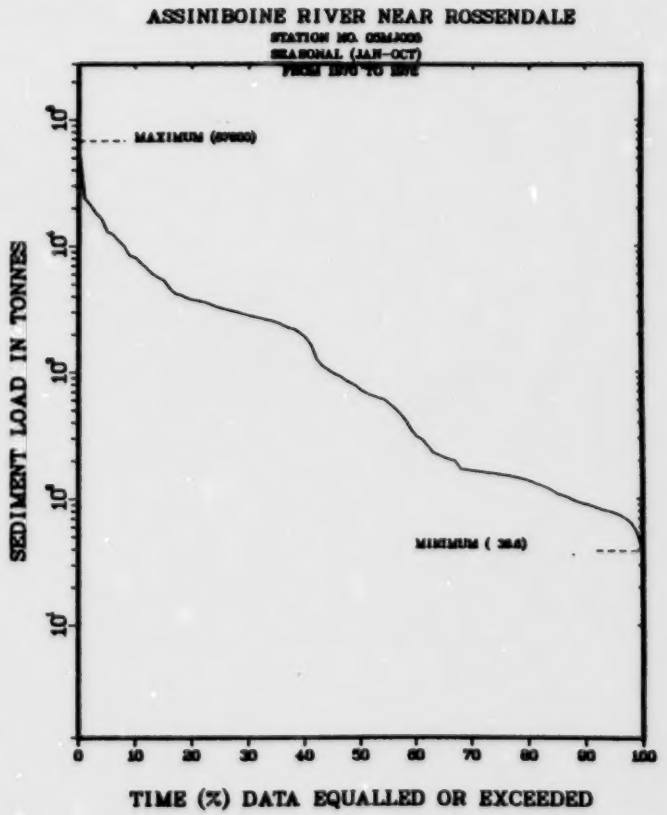


Figure 39 Daily Concentration and Load Duration Curves: Rossendale

- it is not a reliable indication of the long-term variability of annual loads at this station. The mean seasonal flow for 1971 and 1972 is 1 555 000 dam^3, giving a ratio of annual load to annual flow of 419 mg l^{-1}.

7.7 Bed Material Particle Size

There are 8 bed material samples for this station collected between 1970 and 1972 (Fig. 40). Four of the samples were collected with the US BM-54 bucket type sampler and four with the US BMH-53 core type sampler. Mean D_{50} for these samples is 0.502 mm and average grading $[(D_{84}/D_{16})^{0.5}]$ is 2.0. The percent silt/clay is less than 5%, and zero in several samples. All the samples contain some fine gravel, typically 10-15% by weight. Thus, the bed material consists largely of well-sorted medium to coarse sand.

7.8 Suspended Sediment Particle Size

There are 22 particle size analyses of depth-integrating suspended sediment samples (Fig. 40). They were collected at discharges ranging from 24.5 to 501 $m^3 s^{-1}$ and concentrations of 267 to 1 810 mg l^{-1}. D_{50} of these samples ranges from 0.0042 mm to 0.051 mm. Percent sand ranges from 2 to 48% and percent clay from 12 to 49%. Percent sand and D_{50} of the sand show a tendency to increase with discharge (Fig. 41), indicating an element of hydraulic control on suspended sediment transport.

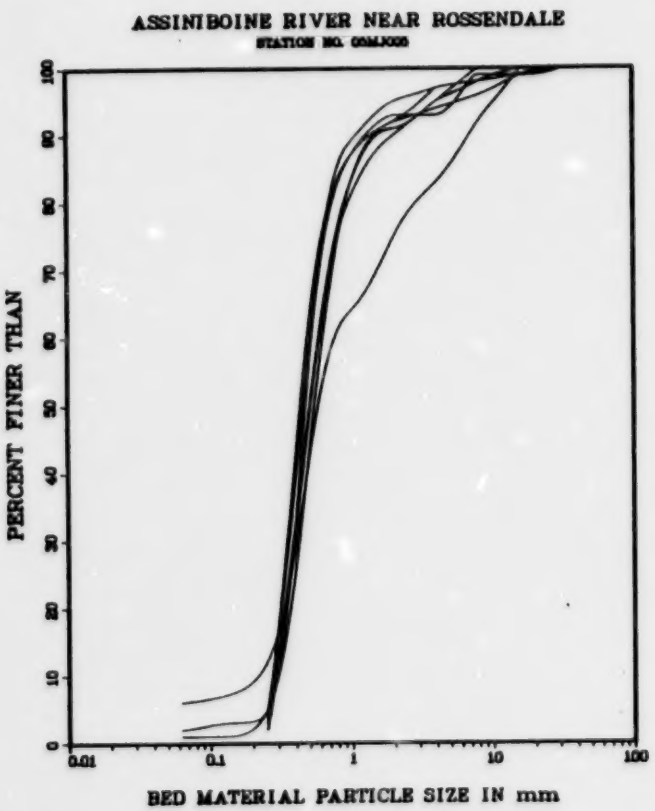


Figure 40 Bed Material and Suspended Sediment Particle Size Distributions: Rossendale

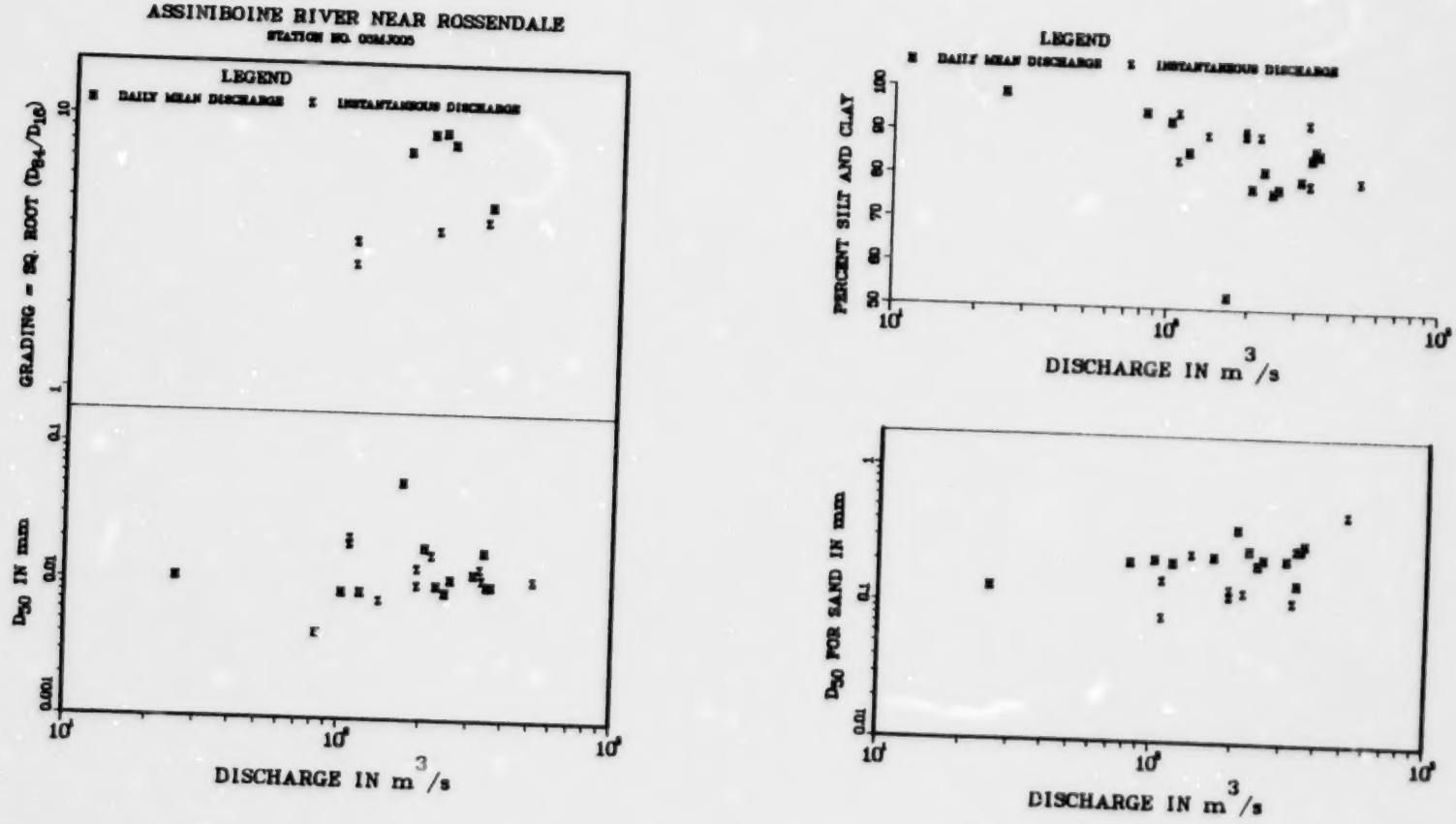


Figure 41 Suspended Sediment Particle Size Characteristics versus Discharge: Rossendale

7.9 Point Integrating Samples

There are two point-integrating measurements at this site: April 28, 1970 (discharge = 501 $m^3 s^{-1}$) and April 19, 1971 (discharge = 188 $m^3 s^{-1}$). Different sampling verticals were used on these two days. Lateral and vertical variation in concentration are greater at the higher discharge (1970). In 1970 the minimum average concentration in a vertical is about 56% of the maximum, compared with 78% in 1971. Silt and clay show very little lateral variability in either sample, but there is a 20-fold range in the average sand concentration between verticals in 1970, and a 2 fold range in 1971.

Silt and clay are distributed almost uniformly in the vertical (average concentration near the surface is between 0.95 and 0.98 of the concentration near the bed). There is a steep vertical concentration gradient for sand, such that sand concentration near the surface averages 20% of that near the bed.

8. ASSINIBOINE RIVER NEAR PORTAGE LA PRAIRIE (05MJ003)

8.1 Station Description and Sediment Program

The sediment program near Portage la Prairie began in 1956, under the direction of PFRA, with seasonal sampling to establish typical loads in the river. After a one year hiatus in 1960, the program was taken over by WRB. In 1961 and 1962 the station was operated on a seasonal basis and converted to continuous in 1963. The continuous program was maintained until 1979, after which the station was discontinued. The main purpose of the station is to monitor the impact of reservoirs and the Portage Diversion on the Assiniboine River (Yuzyk and Penner, 1988).

The station is located at the Hwy 240 bridge crossing 5 km south of Portage la Prairie and 5 km downstream of the Portage Reservoir. The stage recorder shelter is located on the right bank immediately upstream of the bridge. Measurements are made from the bridge, and also from a cableway 2 km downstream of the bridge. The bridge section is about 200 m downstream of the apex of a meander bend, while the cableway is a short distance upstream of a bend apex. The hydrometric station was established in 1921 but operation was discontinued in 1930, and resumed in 1952. Continuous flow records are available for all years from 1953 onward. Flow regulation at Portage Reservoir has altered the natural flow regime at this station, especially by eliminating large flood peaks.

Construction of the Portage Reservoir has affected the vertical and lateral stability of the channel, which was already unstable due to the passage of migratory sand bars. Degradation and channel changes are greatest upstream of the WSC gauge (Pickell, 1984), but at the gauged cross-section the rating curve has shifted downward by 0.4 m between 1970 and 1984, and the channel width has increased by erosion of the right bank of about 6 metres since 1970. In the vicinity of the cableway no significant changes in channel dimensions or bed elevation are apparent.

Geomorphologically, Portage la Prairie marks the transition from the valley incised into the Assiniboine Delta to the section that flows across the Holocene Portage la Prairie 'floodplain fan' (Rannie et al., 1989; Rannie, in press), a predominantly sandy deposit 5 - 10 m thick, overlying the silty clay of the Lake Agassiz sediments. The river here is meandering, sand-bedded. Upstream of Portage the river flows in a valley about 20m deep, but in the vicinity of the WSC station the river is barely entrenched below the surrounding terrain.

Along much of its course between Portage and Headingley the modern river flows along an alluvial ridge with natural levees 1-3 m high. This section of the river is confined by flood control dikes and therefore is no longer actively meandering or undergoing the avulsive changes in course that were responsible for constructing the 'floodplain fan'. The channel contains migratory sand bars and a few small vegetated

islands. Modern point bars are largely vegetated, reflecting the stability of the channel and the regulated flow regime.

The initial years of the sediment program (1956-1959) constituted little more than a miscellaneous program. Samples were collected primarily during the spring flood event only and totalled between 3 and 14 samples per year. When the program resumed in 1961 the data consist of only 3 samples on the falling limb of the spring flood. In 1962 sampling was more thorough and extended from late April to December, however the sampling missed the rising limb and peak of the spring flood. From 1963 onward continuous sampling ensured that all significant flow events were sampled on a normal flow weighted scheme. Since 1956, 2 209 single vertical depth-integrating samples have been collected, and 57% of these (1 269) have been collected at flows equalled or exceeded less than 30% of the time (Fig. 42).

In addition to routine depth-integrating sampling, the sediment program has included bed material sampling (over 60 samples from 1963 to 1979), suspended sediment particle size analysis (approximately 180 samples between 1956 and 1979) and point-integrating samples (9 measurements between 1963 and 1976).

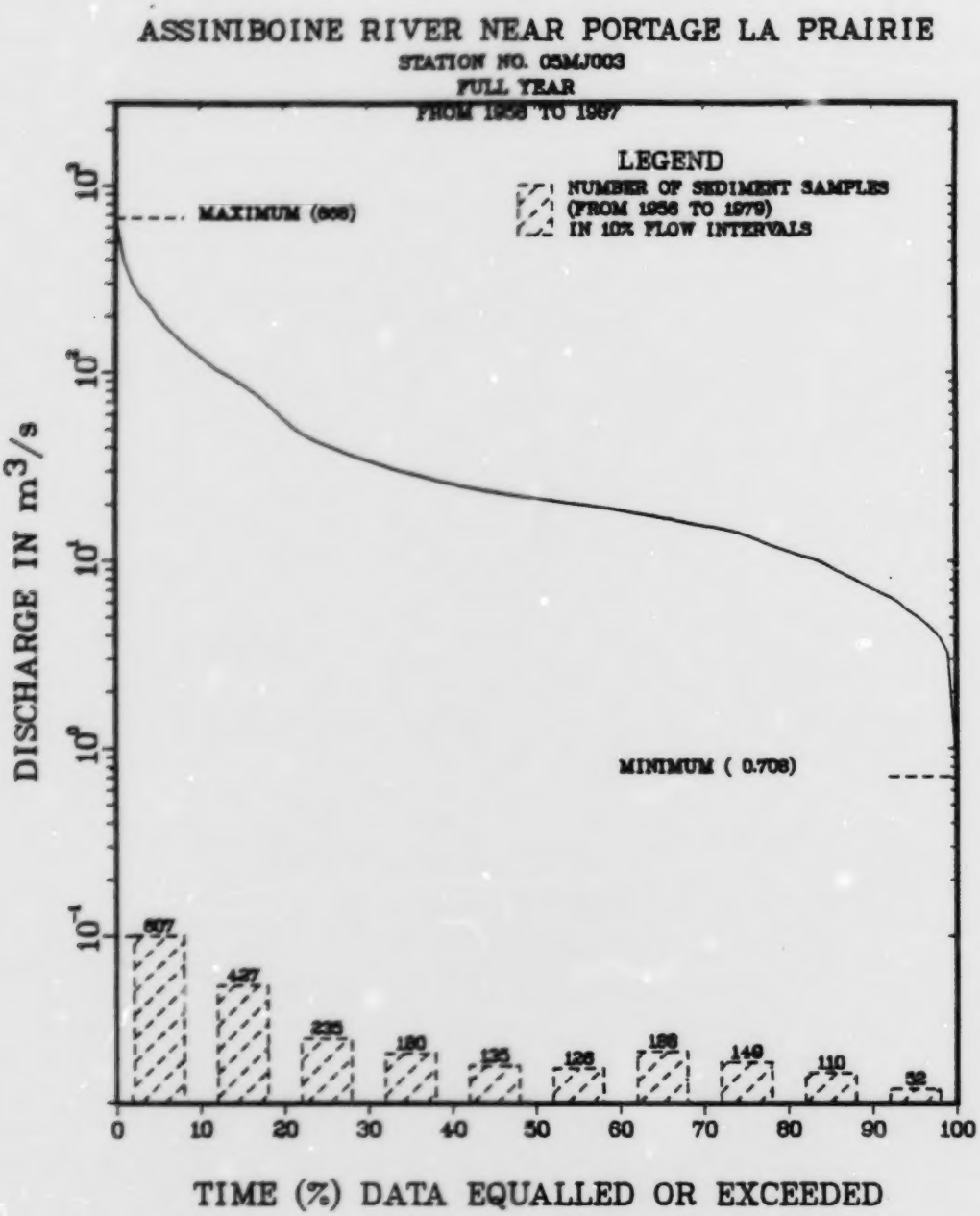


Figure 42 Frequency of Sediment Sampling: Portage

8.2 Flow Coverage

Sampling has covered all the flood peaks since 1963. This covers 8 years prior to construction of the Shellmouth Dam and Portage Diversion and 9 years of post-regulation flows. Because continuous flow records only began in 1953, these 17 years of continuous sediment program and 6 years of seasonal sampling cover most of the range of flows experienced since 1953. The period of continuous sampling includes the largest and second smallest annual maximum floods (668 and 49.8 $m^3 s^{-1}$ in 1976 and 1977 respectively) as well as the second highest and second lowest total annual flow (Fig. 43) for the period 1953 to 1987. Thus, the range of annual total and annual maximum discharges is well covered. The continuous sampling program has also ensured adequate coverage of low flow conditions.

8.3 Annual Discharge and Sediment Regime

Flow regulation by the Portage Reservoir (and to some extent the additional effect of the Shellmouth Dam) has had a considerable effect on the flow regime of the Assiniboine River near Portage (Fig. 44). The natural flow of the river is typical for the Assiniboine River system, with an annual peak in late April and a gradual decline through the summer and fall. The exact effect of flow regulation on the flow regime varies from year to year depending upon the operation of the Portage Diversion.

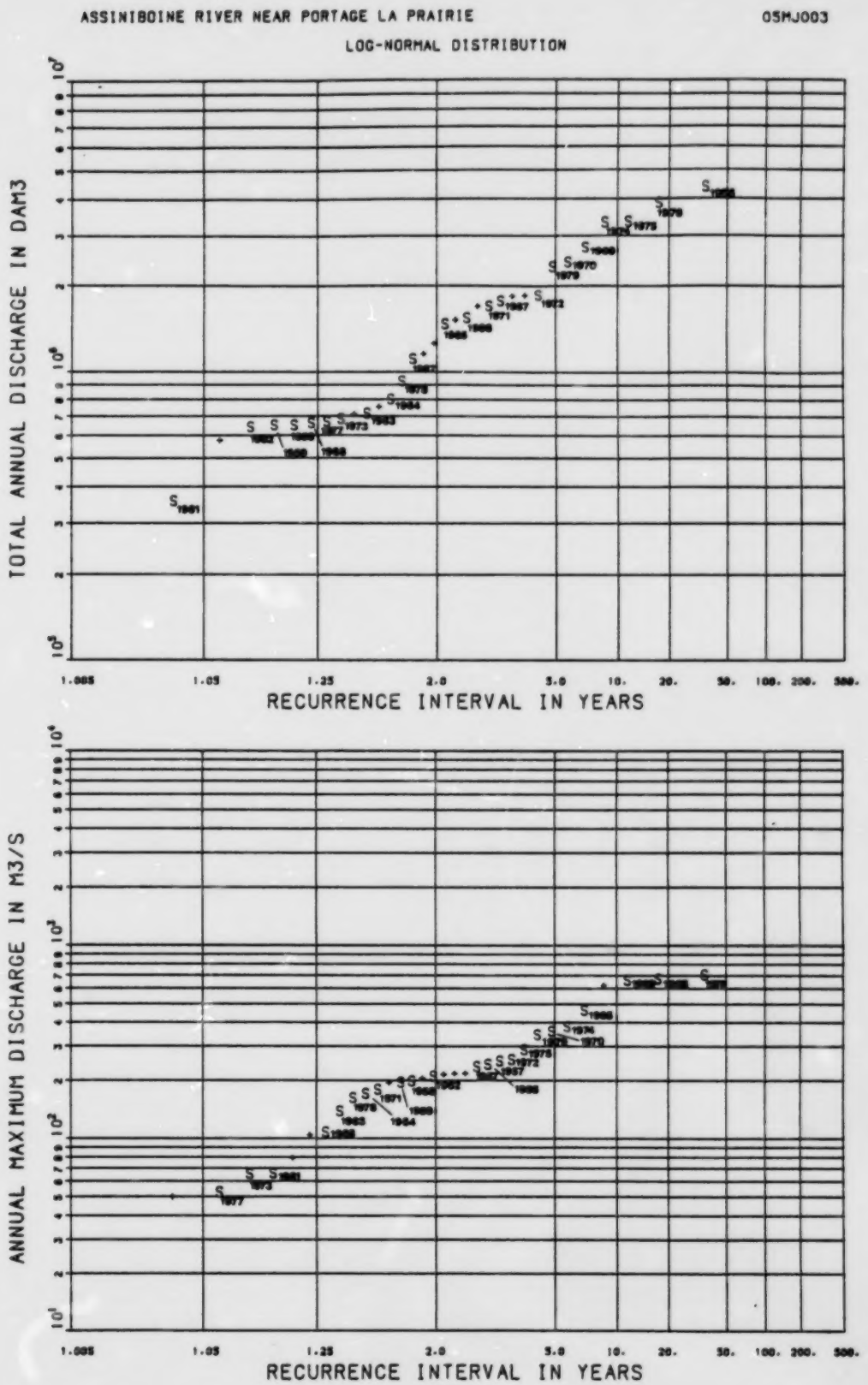


Figure 43 Coverage of Extreme Discharges: Portage

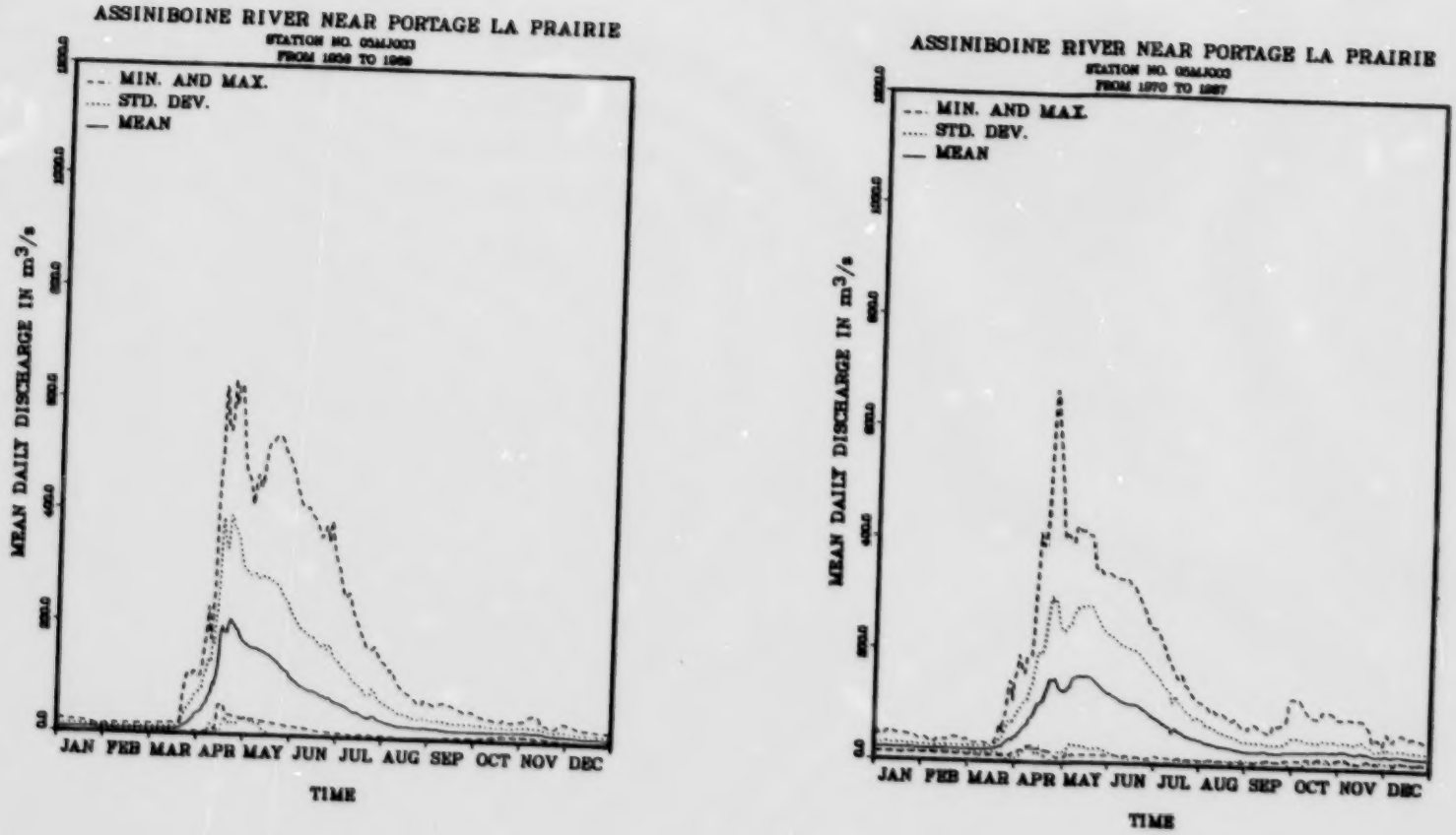

ASSINIBOINE RIVER NEAR PORTAGE LA PRAIRIE
STATION NO. 05MJ003
FROM 1909 TO 1969
--- MIN. AND MAX.
..... STD. DEV.
— MEAN
MEAN DAILY DISCHARGE IN m3/s
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME
ASSINIBOINE RIVER NEAR PORTAGE LA PRAIRIE
STATION NO. 05MJ003
FROM 1970 TO 1987
--- MIN. AND MAX.
..... STD. DEV.
— MEAN
MEAN DAILY DISCHARGE IN m3/s
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME

Figure 44 Effect of the Portage Diversion on the Annual Hydrograph at Portage la Prairie

The monthly flows through the Diversion are listed in Table 3 for all the years of operation up to 1986. During the period of sediment record there are two years since construction of the diversion in which no flow was diverted - 1973 and 1977. The operating rules for the diversion are fairly complex but in principle they depend upon diverting sufficient flow during flood events to prevent flood levels exceeding a critical height in the City of Winnipeg, which is the primary objective of the operation of the Diversion (Toye, 1984). At the same time the capacity of the Diversion and of the dikes on the Assiniboine downstream of Portage, as well as the water level of Lake Manitoba, and the formation of ice jams on the Assiniboine River have to be taken into account. The reservoir is drawn down in winter to a minimum level usually in January, prior to filling during the spring flood. The level is then maintained through the summer prior to draw down in September or October.

The Diversion has a capacity of 708 $m^3 s^{-1}$ but there is a failsafe section near the downstream end which breaches at 425 $m^3 s^{-1}$. The Assiniboine River downstream of Portage has a capacity of 566 $m^3 s^{-1}$ within the dikes. If predicted water levels in Winnipeg exceed 5.2 m above the local datum, or if the predicted inflow to the Portage Reservoir is greater than 566 $m^3 s^{-1}$, then the Diversion is opened. In addition, if there is ice on the Assiniboine River, discharge downstream of Portage is maintained below 142 $m^3 s^{-1}$, to allow flushing of the channel, and whenever possible, discharge downstream of Portage is kept below the natural bankfull discharge of 283 $m^3 s^{-1}$.

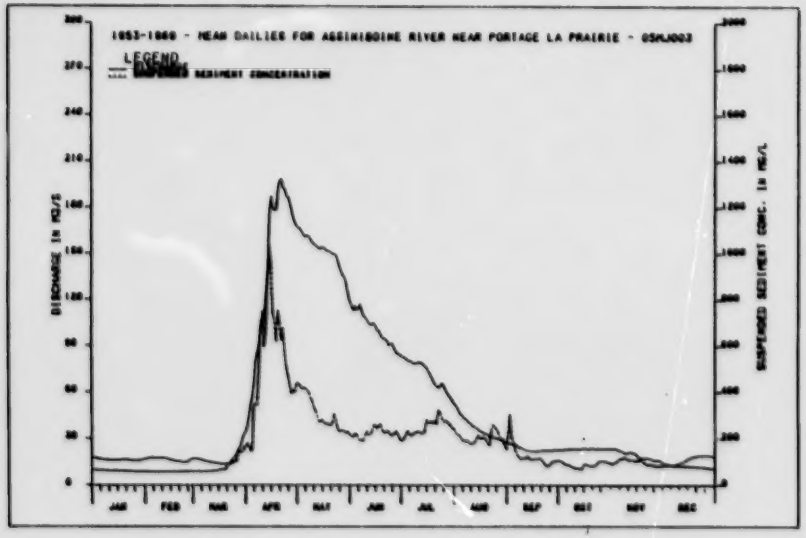
TABLE 3 Monthly Mean Discharges: Portage Diversion near Portage la Prairie

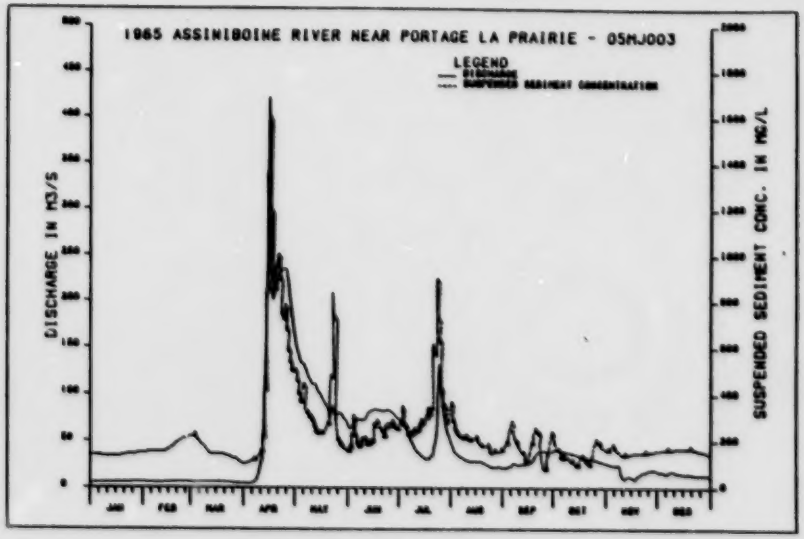
Year	March	April	May	June	July
1970	0	57.1	42.4	0	0
1971	0	12.1	0	0	0
1972	7.59	102	7.79	0	0
1973	0	0	0	0	0
1974	0	143	93.6	10.4	3.43
1975	0	43.6	144	63.5	0
1976	0	469	198	2.29	0
1977	0	0	0	0	0
1978	0	1.62	0	0	0
1979	0	65.6	147	34.2	0
1980	0	0	0	0	0
1981	0	0	0	0	0
1982	0	14.0	0	0	0
1983	0	55.6	5.93	0	0
1984	0	0	0	0	0
1985	17.7	2.95	0	0	0
1986	6.02	22.1	15.8	0	0

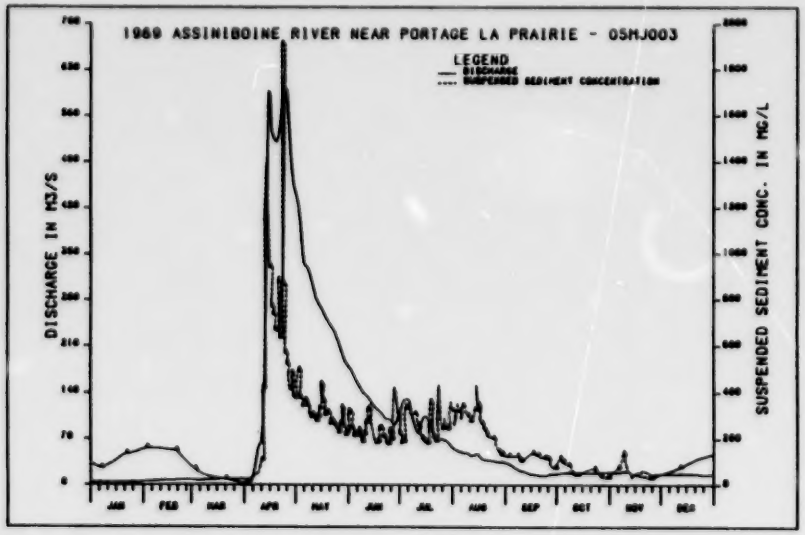
In an emergency, if the inflow to the reservoir is greater than the combined capacity of the Diversion and the dikes (1 274 $m^3 s^{-1}$), flow in the Diversion is maintained below 708 $m^3 s^{-1}$ and the surplus is allowed to overtop the Assiniboine River dikes.

Generally, the operation of the Portage Diversion has involved diversion of spring flood discharges out of the Assiniboine River so that typically there is flow in the Diversion during April, May and June. The result of this has been to eliminate many flood peaks downstream of the Portage Reservoir, to reduce average daily discharge in April (from over 200 to about 150 $m^3 s^{-1}$) and May and to augment flows during the summer, fall and winter by drawdown of the Portage and Shellmouth Reservoirs. In addition, the spring discharge peak downstream of the reservoir is often delayed by the reservoir filling and flow diversion (Fig. 44 and 45). The average date for peak discharge is about 14 days later during years when the Diversion is operated than under natural flow conditions, and there is a greater tendency for two discharge peaks (in late April and in mid-May) rather than a single peak in late April. There has also been a slight reduction in average annual flow when compared with calculated natural flow (Prairie Provinces Water Board, 1982). In a typical year in which flow is diverted the flow regime would resemble that for 1974 in Figure 45.

Prior to flow regulation, the suspended sediment concentration followed the annual hydrograph fairly closely. Peak sediment concentration (usually 1 000 to 3 000







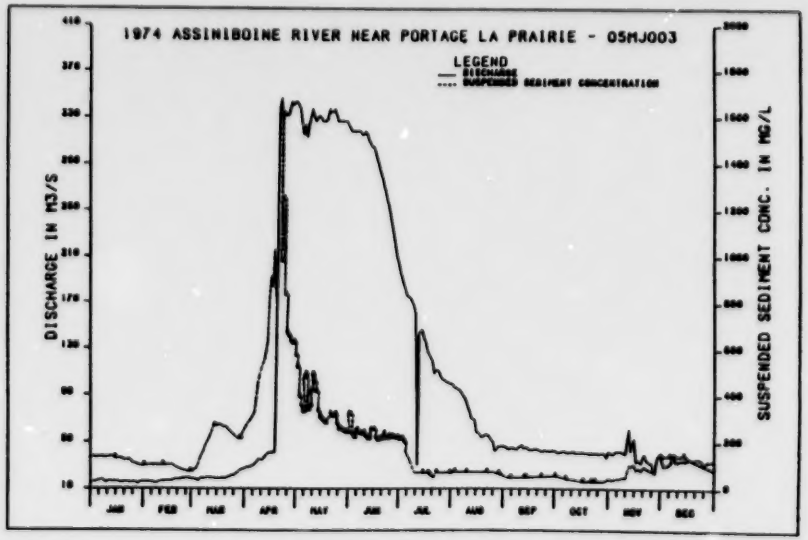
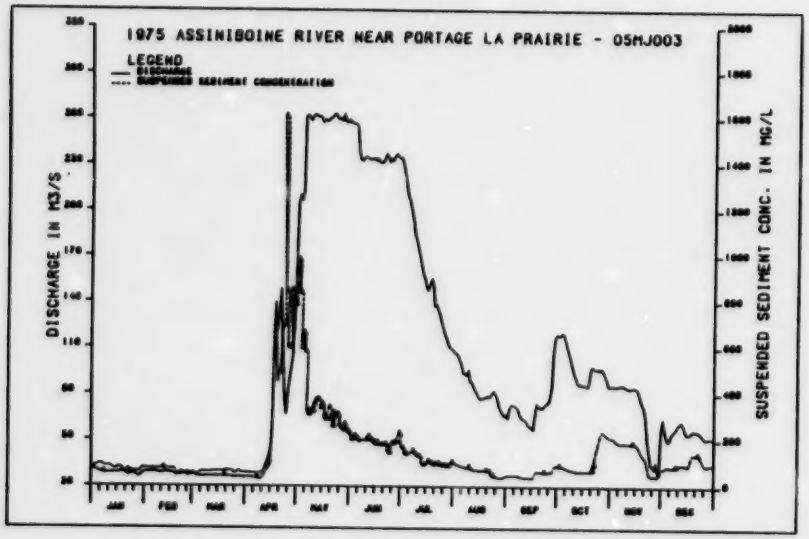
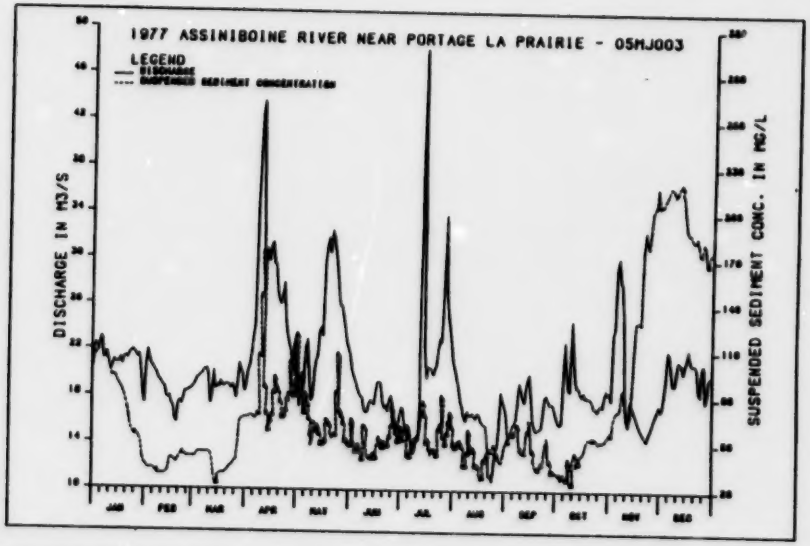


Figure 45 Examples of Annual Hydrographs and Sediment Regimes: Portage





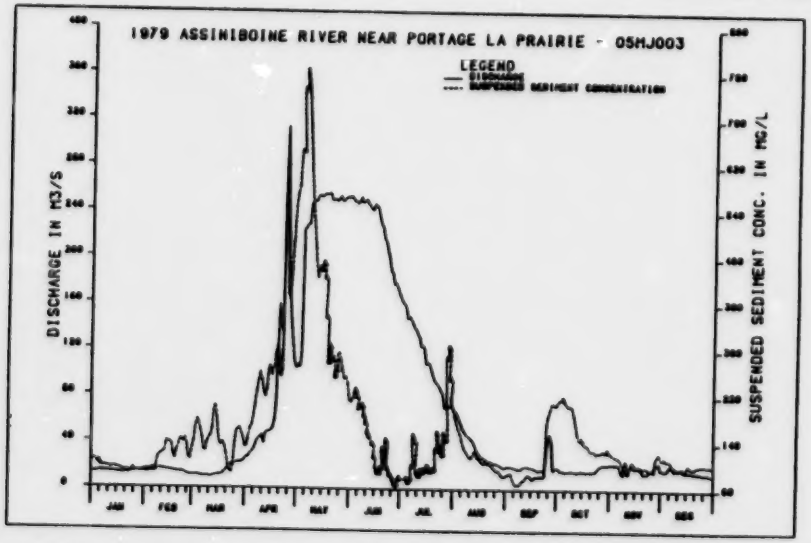


Figure 45 Continued

mg l^{-1}) coincided with peak discharge and then declined rapidly to less than 200 mg l^{-1} after the spring flood, with occasional increases due to summer flood events (Fig. 45, 1953-1969, 1965 and 1969). Subsequently the annual concentration regime has been modified, particularly during the period of flow diversion in the spring. Peak concentrations (ranging from 300 to 2 000 mg l^{-1}) still occur in late April or early May, but do not necessarily coincide with peak discharge.

In the years in which the discharge peak is delayed by reservoir filling and diversion, the peak suspended sediment concentration commonly precedes the flood peak, often by a week or more (1970, 1972, 1975, 1976). In other years the two coincide (1974) and in two years the sediment concentration peak occurred after the discharge peak (1978, 1979). In low flow years such as 1973 and 1977 the timing of peak discharges and concentrations is much more erratic and not subject to control by the Diversion. Examples of all these patterns are shown in Figure 45.

8.4 Daily Mean Suspended Sediment Concentration

The most important aspect of the mean daily suspended sediment concentrations at this station is the reduction in average concentrations since the opening of the Portage Diversion (Fig. 46). There is considerable scatter (greater than an order of magnitude) about the ordinary least squares regression lines for both the pre and post-Diversion data, but nevertheless there are discernible differences between the two data

sets. For example, predicted concentrations at 10, 100 and 400 $m^3 s^{-1}$ prior to 1970 are 112, 337 and 654 mg l^{-1} respectively. After 1969, under the influence of the Diversion, these same discharges have predicted concentrations of 43, 149 and 315 mg l^{-1} - a reduction in average concentration of greater than 50% in each case. Sediment trapping in the Reservoir, combined with a disproportionate amount of sediment being diverted compared to the volume of water, probably combine to cause this effect.

8.5 Suspended Sediment Concentration and Load

Duration curves for daily concentration and load are shown in Figure 47. For the full period of record (incorporating both pre and post-Diversion data) the median daily concentration is 121 mg l^{-1}, with a maximum of 3 081 mg l^{-1}. Concentrations of 300 mg l^{-1} are equalled or exceeded 10% of the time. Median daily load is 220 Mg, with a maximum of 103 000 Mg. Daily loads of 1 000 Mg are equalled or exceeded 20% of the time.

When separated into pre and post Portage Diversion time periods (Fig. 48) some alterations in the sediment regime are apparent, particularly in the daily concentration duration curve. Median daily concentration dropped from 146 mg l^{-1} to 103 mg l^{-1} and concentrations of 300 mg l^{-1} are exceeded 14% of the time prior to 1970 and only 7% of the time afterwards. In contrast, the median daily loads increased

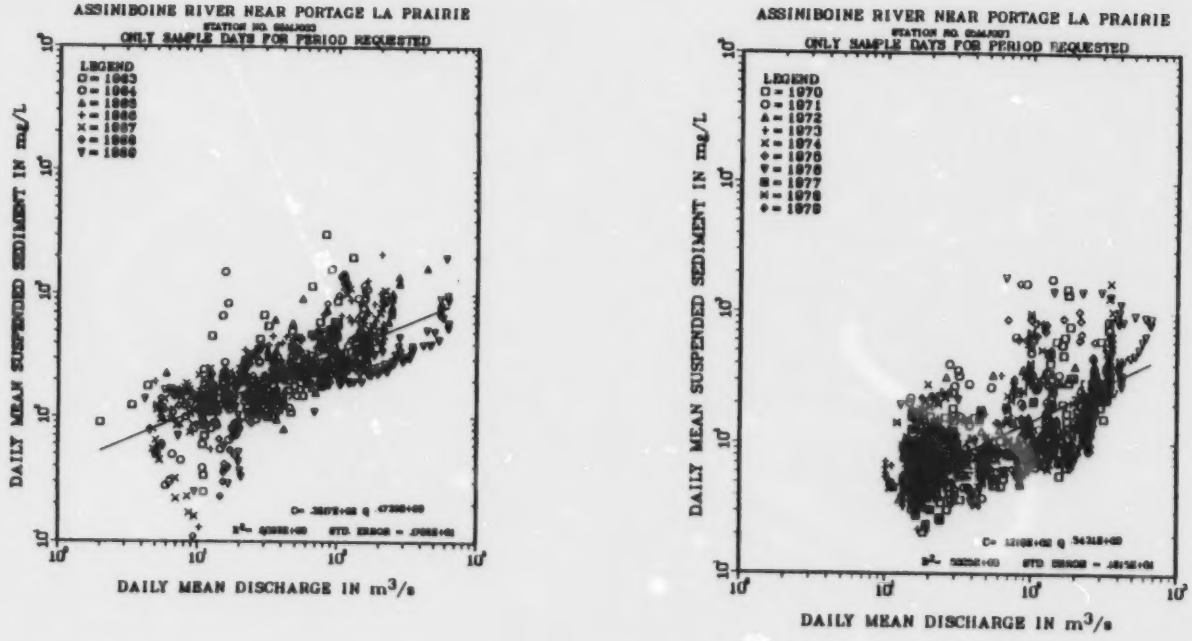
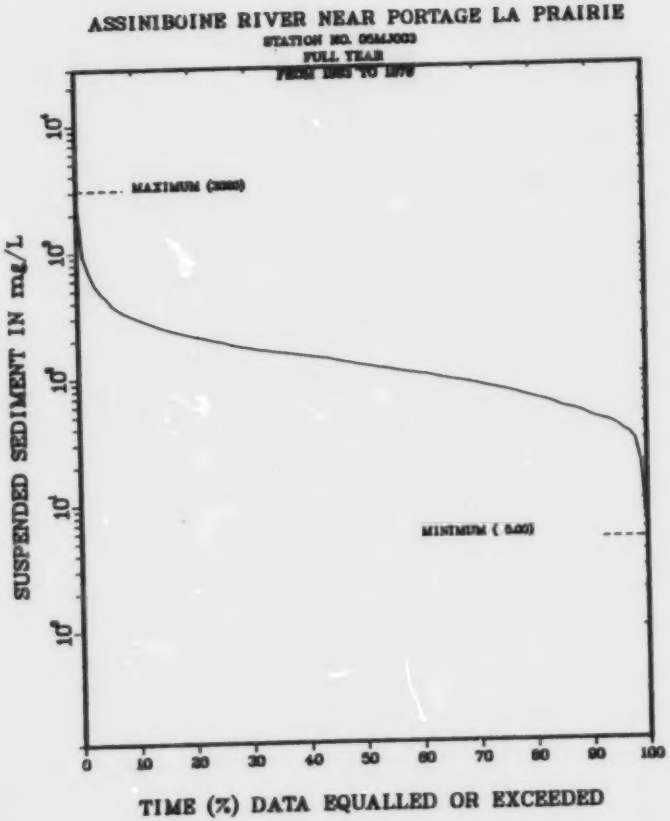


Figure 46 Effect of the Portage Diversion on the Relationship Between Daily Mean Suspended Sediment Concentration and Discharge at Portage la Prairie



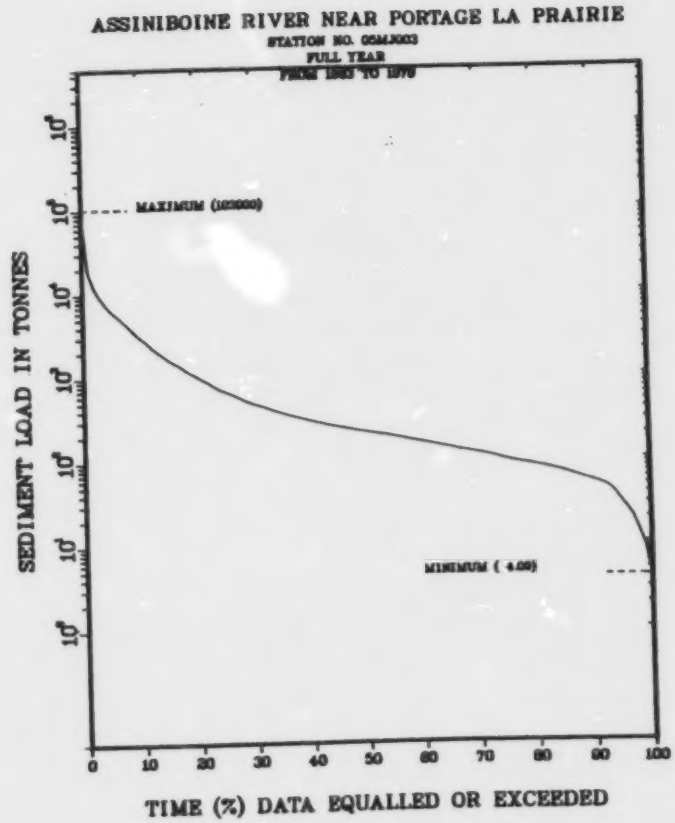
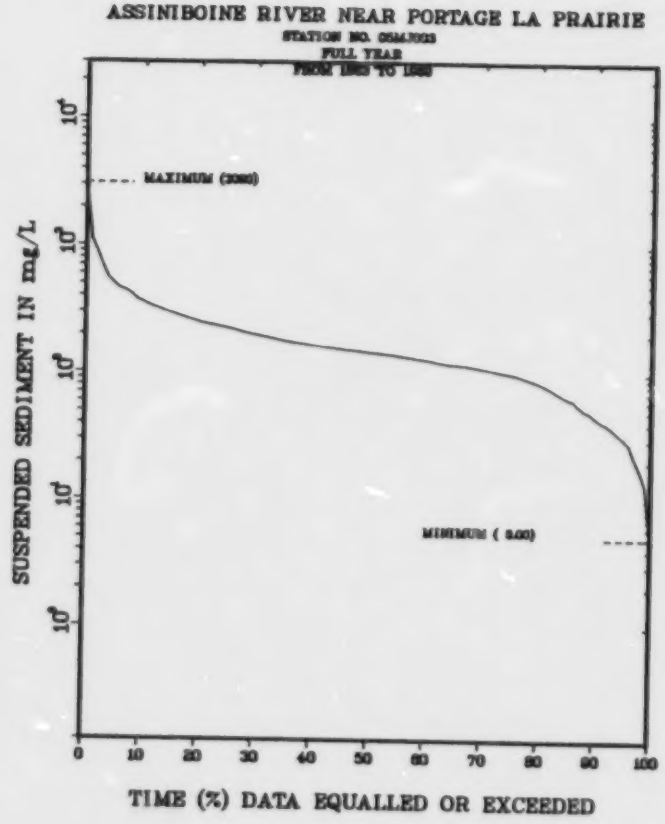


Figure 47 Daily Concentration and Load Duration Curves: Portage



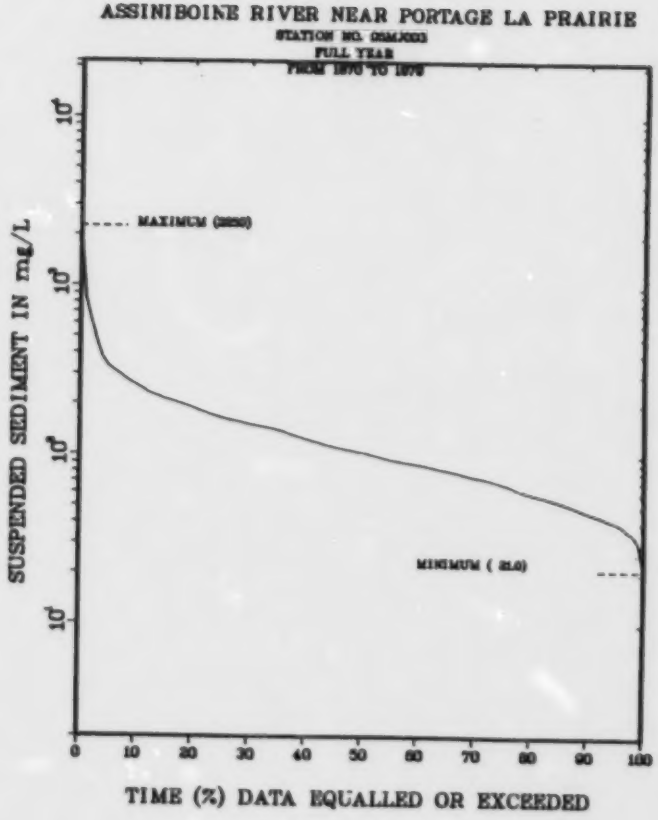
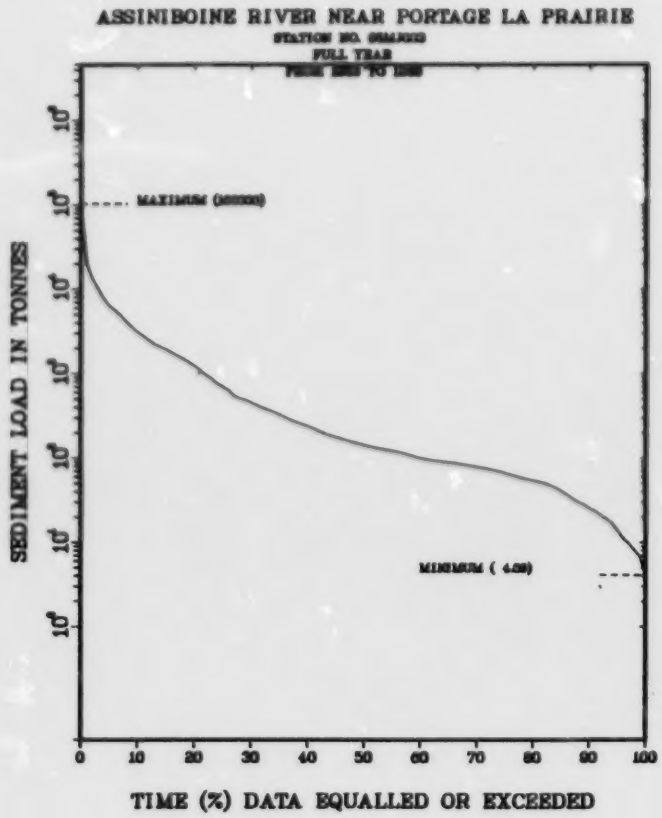


Figure 48 Effect of the Portage Diversion on Daily Concentration and Load Duration Curves



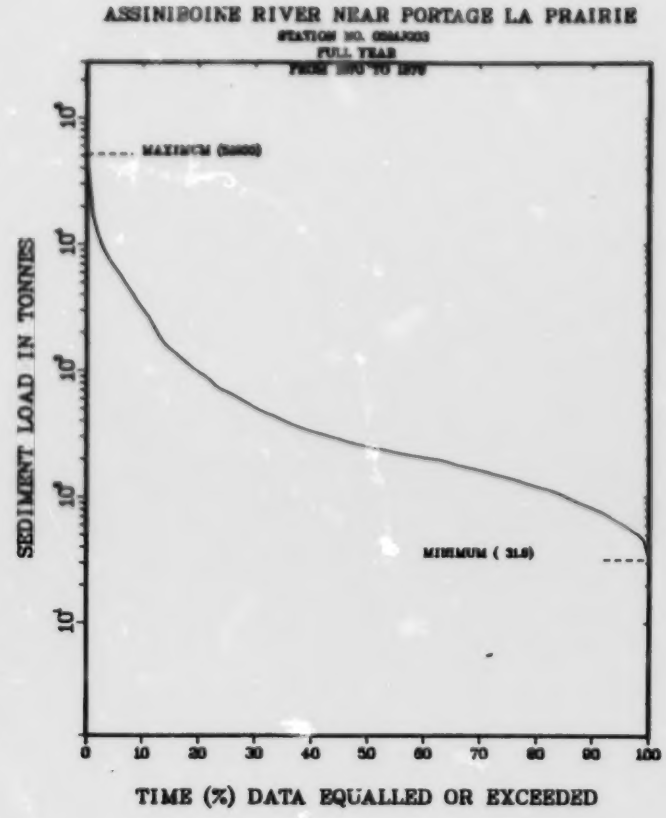
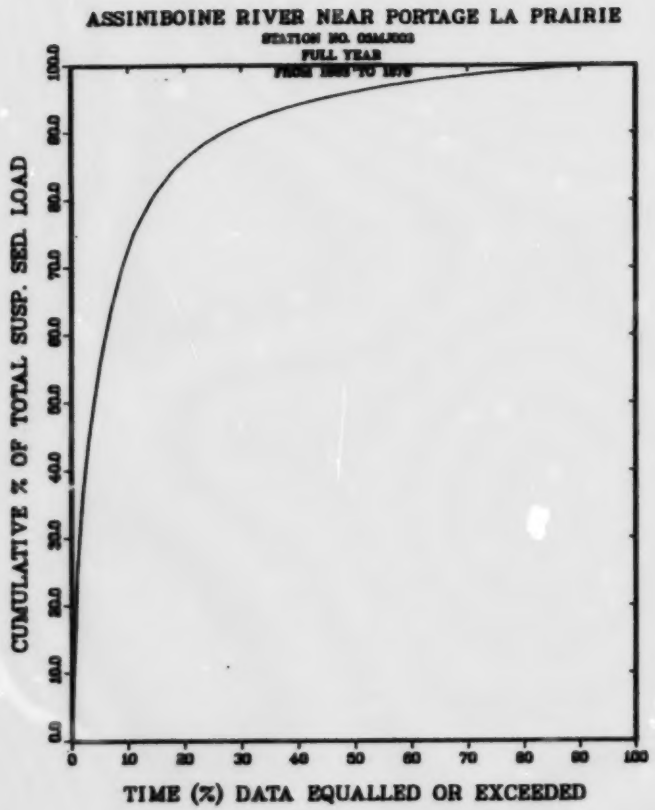


Figure 48 Continued

after the opening of the Diversion, presumably because the higher flows during this period outweighed the reductions due to flow diversion.

For the full period of record, 80% of the annual load is transported, on average, in 14 % of the time (Fig. 49). This changed little as a result of the Diversion (12 % prior to the Diversion and 15 % afterwards). The 'effective' discharge range (Fig. 49) is 233 to 267 $m^3 s^{-1}$ which has a duration of 3 - 5.5%. Prior to 1970 the 'effective' discharge was considerably lower (133 - 167 $m^3 s^{-1}$, duration range = 8 - 11%), but the extreme discharges, exceeded less than once per year, transported almost as much as the effective discharge, giving a bimodal effective discharge histogram (Fig. 50). The effect of flow regulation has been to reduce the efficacy of the large discharges and enhance the total load transported by flows in the middle portion of the range.

The average highest 4 and 37 consecutive day loads are, respectively, 14 and 57 % of the annual load (Fig. 51). After the construction of the Portage Diversion the average 4 consecutive day load decreased from 19 to 11 % of the annual load, and the 37 consecutive day load from 68 to 49 % of the annual load. Thus, the regulated regime after the construction of the Diversion has resulted in the sediment load of the river being spread over a wider range of discharges and longer period of time - the peak discharges are proportionally less dominant in the transport of the annual load.


ASSINIBOINE RIVER NEAR PORTAGE LA PRAIRIE
STATION NO. 05ML003
FULL YEAR
CUMULATIVE % OF TOTAL SUSP. SED. LOAD
TIME (%) DATA EQUALLED OR EXCEEDED

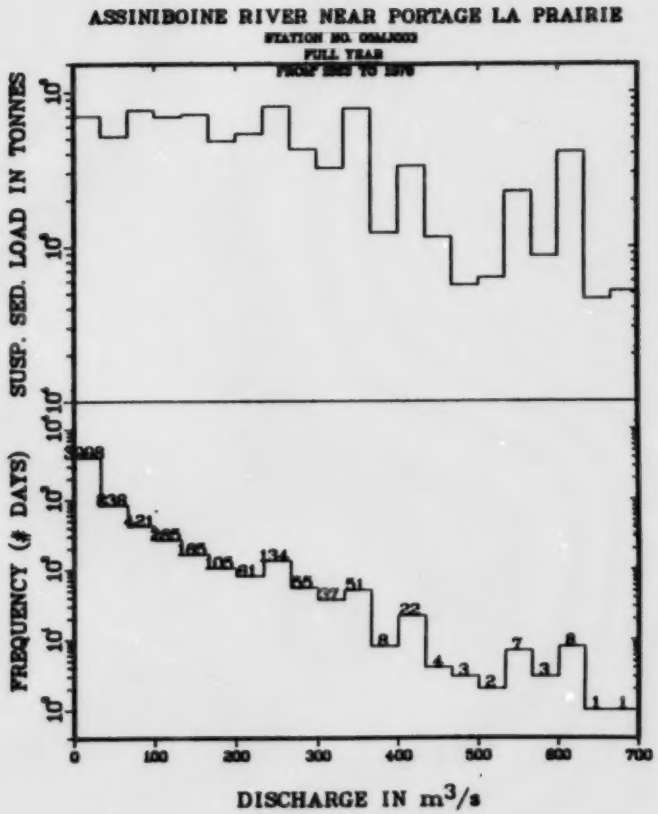
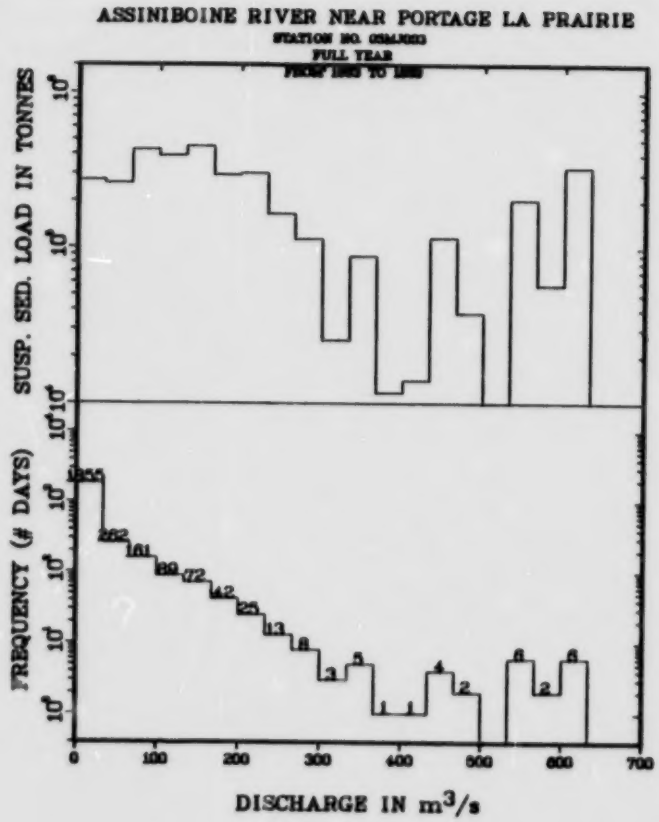


Figure 49 'Effective' Discharge and Cumulative Load Duration Curve: Portage, 1963 - 1979



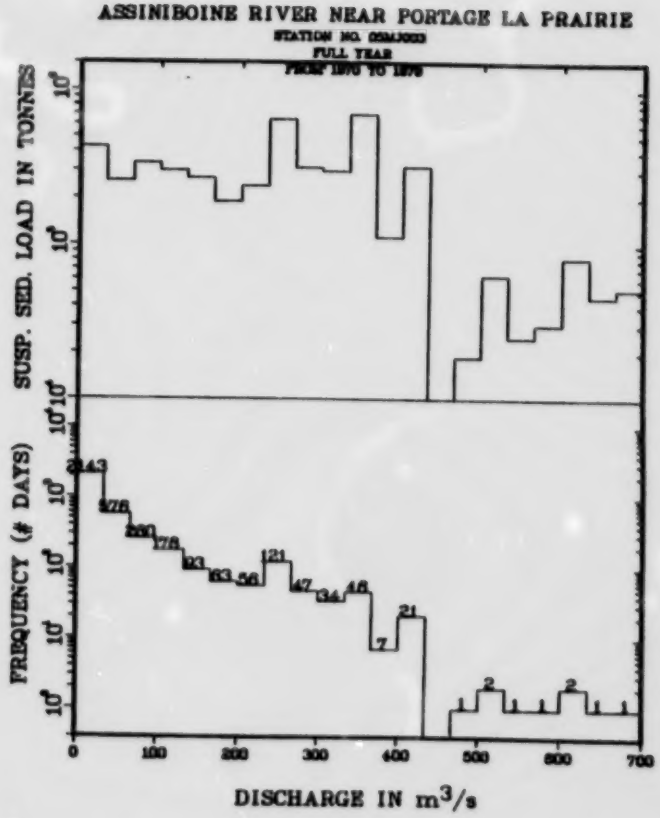


Figure 50 'Effective' Discharge Diagrams Showing the Influence of the Portage Diversion

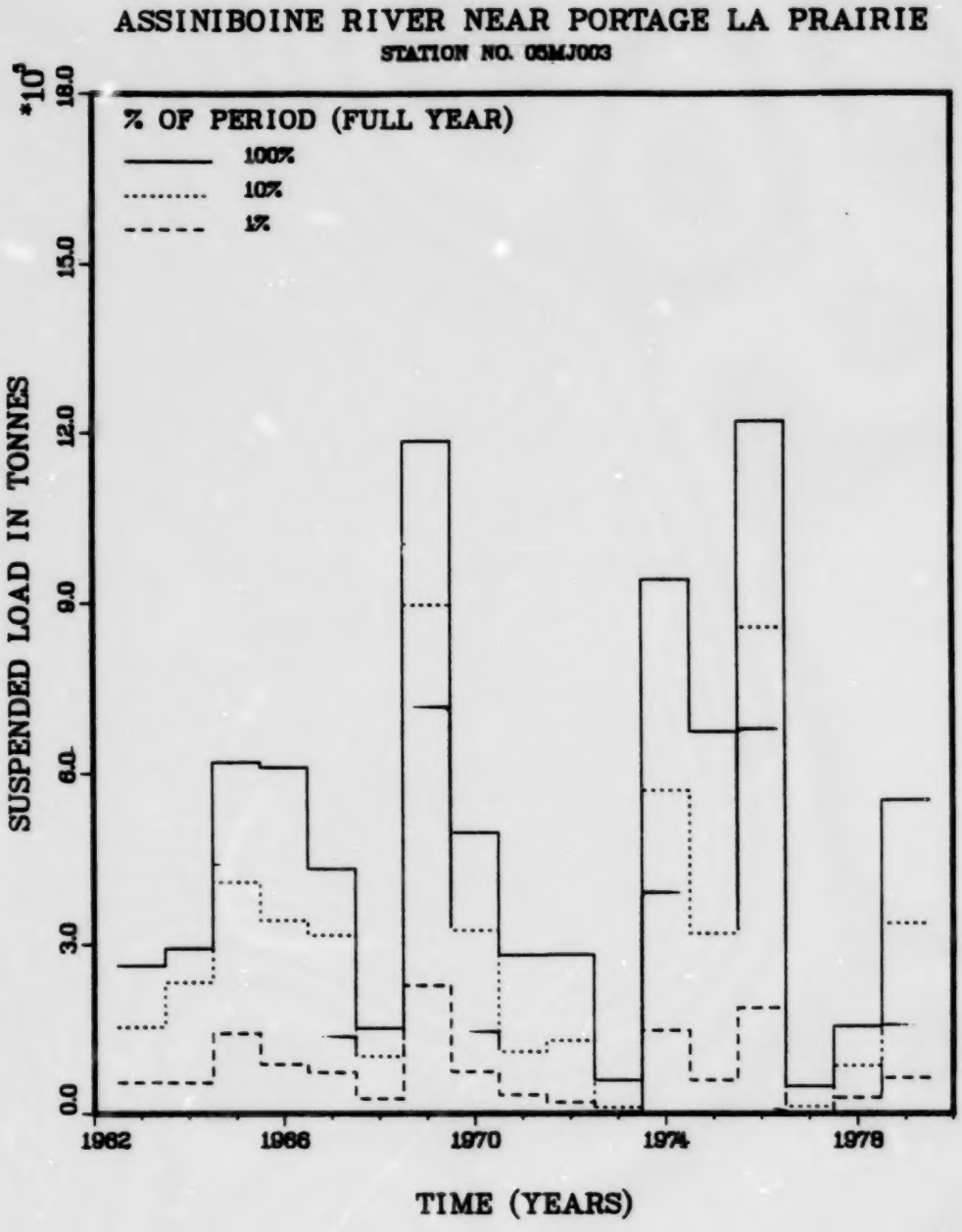


Figure 51 'Best Percent' of the Annual Load: Portage

8.6 Total Annual Sediment Load and Yield

Mean annual load of the Assiniboine River near Portage la Prairie for the period 1963 to 1979 is 487 000 Mg with a standard deviation of 360 000 Mg and standard error of the estimate of the mean of 18%. When divided into two time periods, before and after construction of the Diversion, the mean annual loads are 508 000 Mg and 472 000 Mg for 1963 -1969 and 1970-1979 respectively. Both of these estimates have standard errors of about 26%. Annual loads range from a low of 48 900 Mg in 1977 to a high of 1 220 000 Mg in 1976. Of the cumulative load of 8 270 000 Mg transported in the 17 years from 1963 to 1979, approximately 50% (4 020 000 Mg) was carried in the four highest years, 1969, 1974, 1975 and 1976. Mean annual total discharge from 1963-1979 is 1 710 000 dam^3, giving an average ratio of annual load to annual flow of 284 mg l^{-1}.

Although the mean annual loads before and after the Diversion differ by very little, the mean annual flows for the period after construction of the Portage Diversion are higher (2 040 000 dam^3) than for the period 1963 to 1969 prior to construction of the Diversion (1 240 000 dam^3), despite the Diversion of considerable volumes of water out of the Assiniboine River in some years. Therefore, it is apparent that the annual loads for the period 1970 to 1979 are lower than they might have been in the absence of the Diversion channel.

This change in the sediment regime can be demonstrated from the existing annual load and flow data in several ways. The ratio of the mean annual load to mean annual flow prior to the Diversion is 408 mg l^{-1} and after the Diversion is 231 mg l^{-1}. In other words there is a clear decline in average annual suspended sediment concentrations after operation of the Diversion began. The plot of annual mean concentration versus annual mean discharge (Fig. 52) shows a striking tendency for the years prior to 1970 to plot above the regression line and those from 1970 on to plot below it. This is also a clear indication of a decline in average concentration (and hence load) for a given annual discharge after operation of the Diversion began. This is further reflected in the plot of cumulative load versus cumulative discharge (Fig. 53) which shows a break in a slope between 1969 and 1970 suggestive of a general change in the relationship between annual load and annual discharge.

8.7 Bed Material Particle Size

Figure 54 shows the particle size distribution curves for the 64 bed material samples from the Assiniboine river near Portage la Prairie collected between 1963 and 1979. The majority (42 of the 64) were collected prior to 1970. Four standard samplers have been used: BM-54 (27 samples), BMH-53 (20 samples), Scoop (6 samples) and Lane (Canadian Drag Bucket) (11 samples). In all cases the bed material is well-sorted, medium-coarse sand. Mean D_{50} for all 64 samples is 0.442 mm, with a standard deviation of 0.058 mm. The mean sorting coefficient $[(D_{84}/D_{16})^{0.5}]$ is

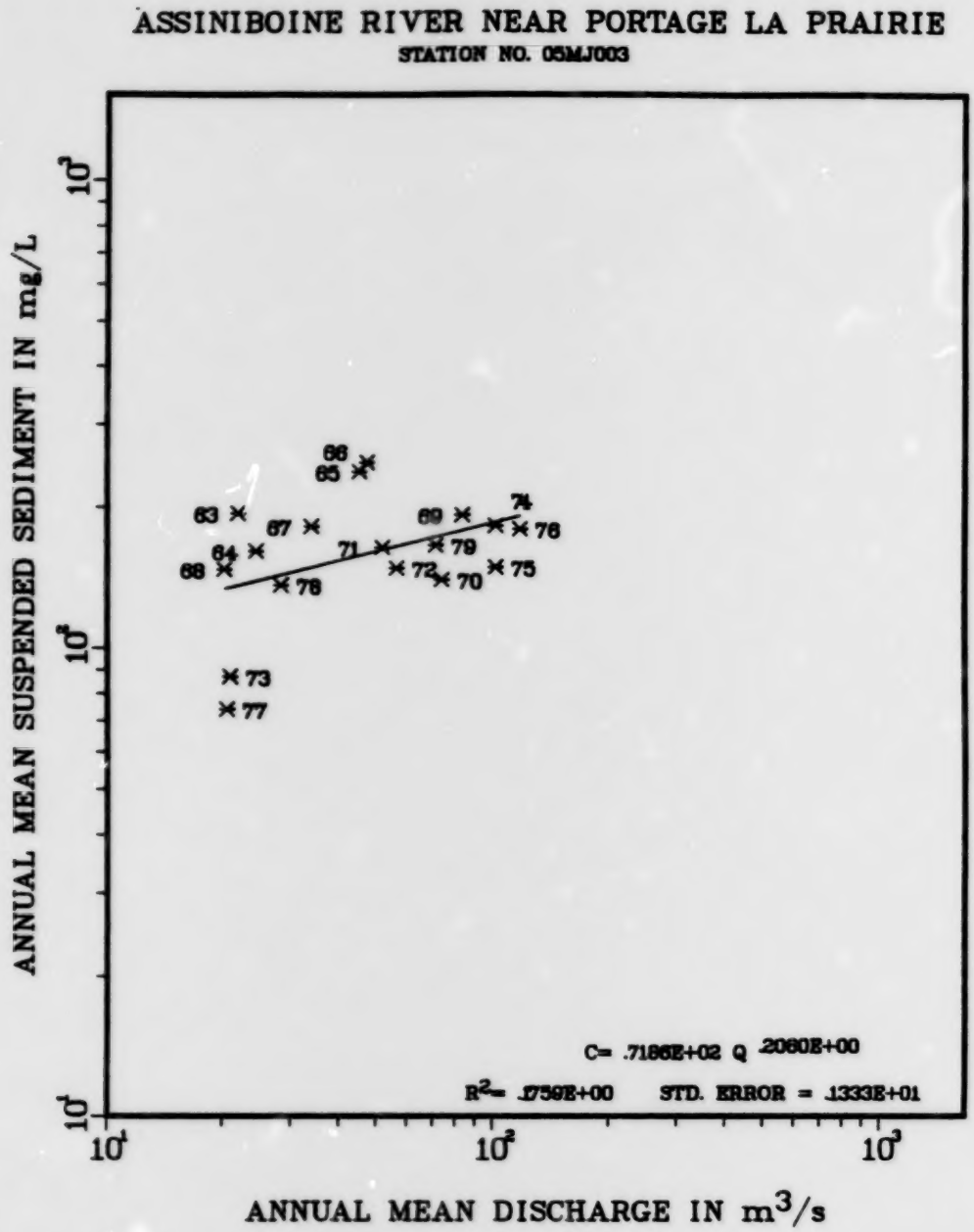


Figure 52 Mean Annual Suspended Sediment Concentration versus Mean Annual Discharge: Portage

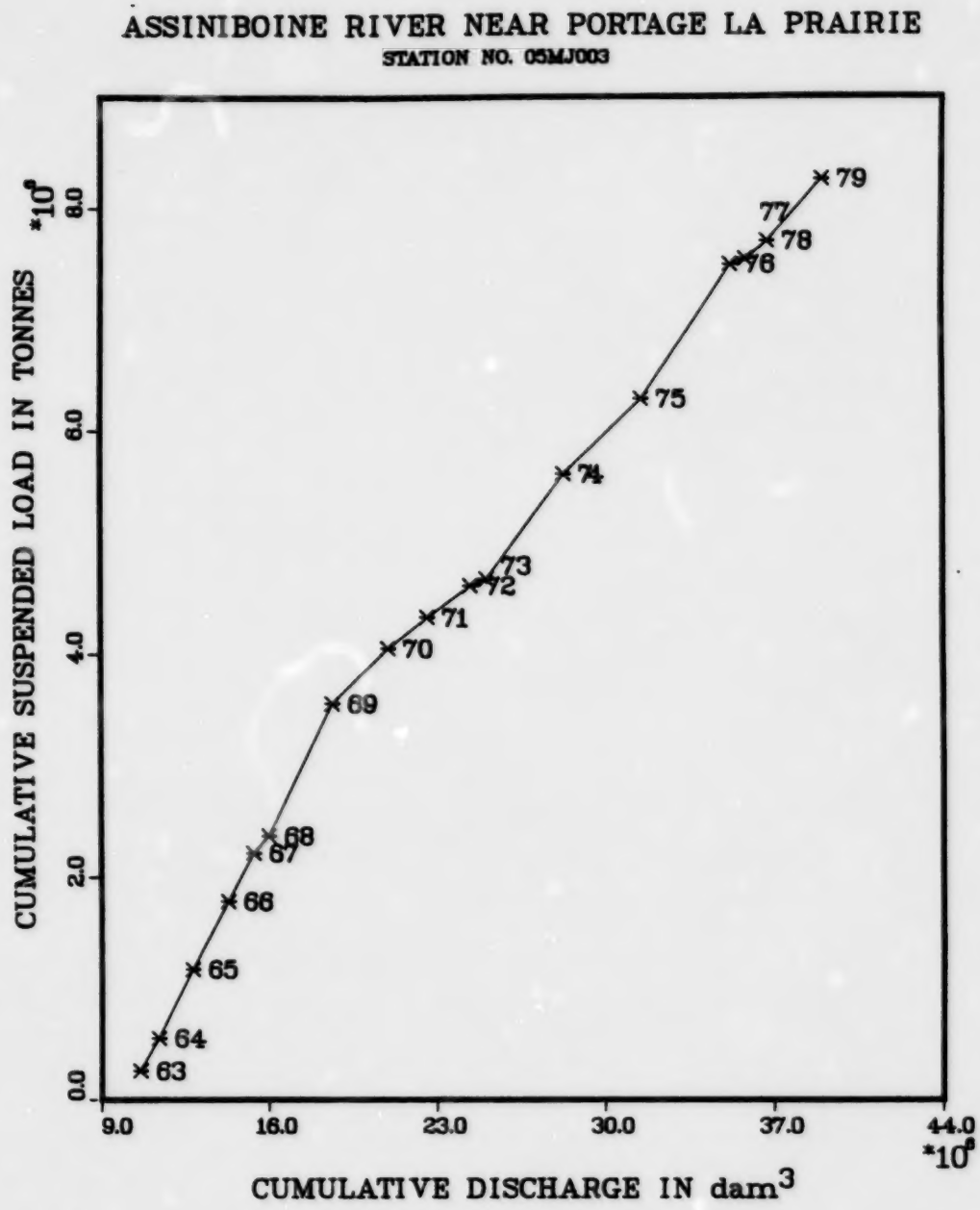


Figure 53 Cumulative Suspended Sediment Load versus Cumulative Discharge: Portage

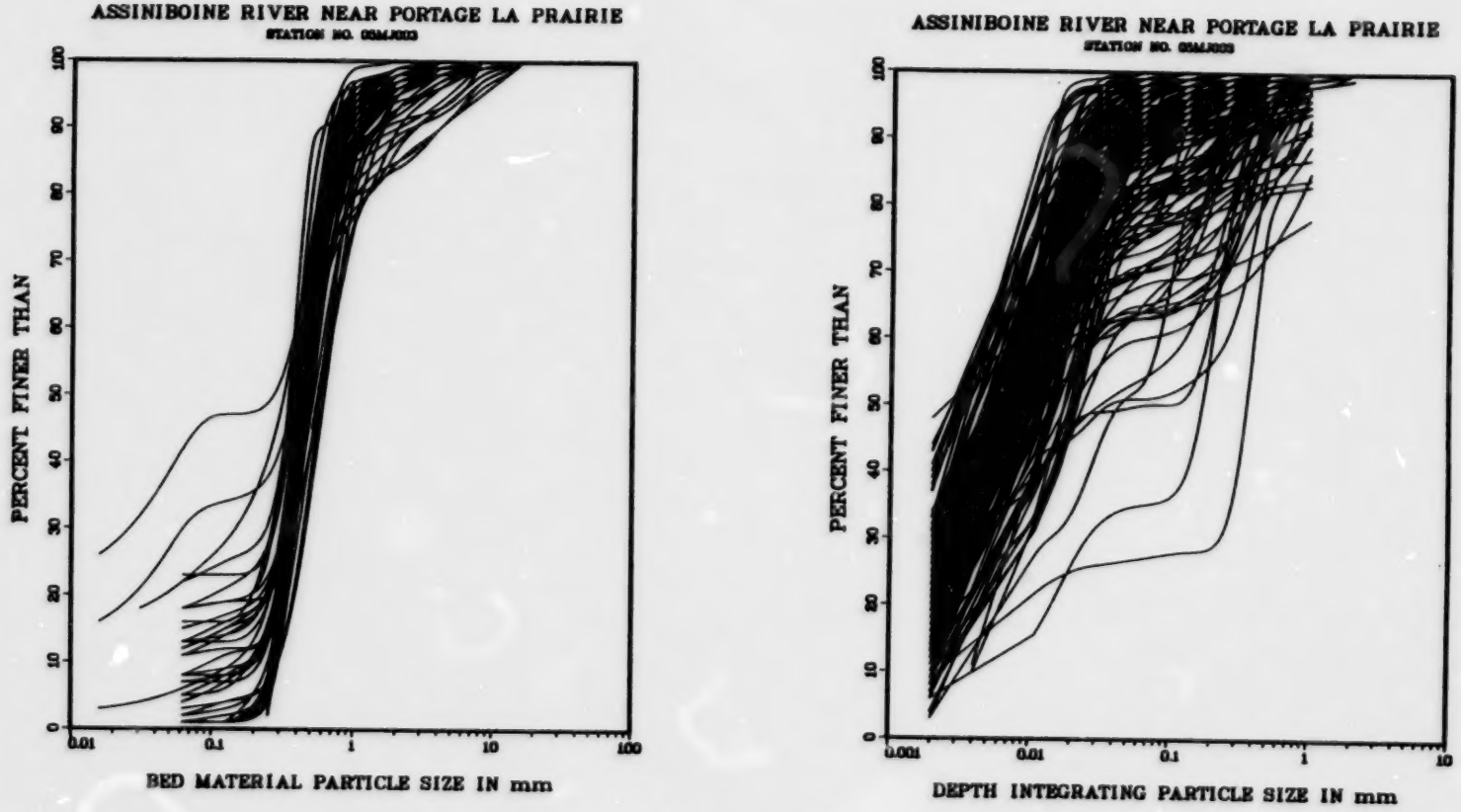

ASSINIBOINE RIVER NEAR PORTAGE LA PRAIRIE
PERCENT FINER THAN
BED MATERIAL PARTICLE SIZE IN mm
ASSINIBOINE RIVER NEAR PORTAGE LA PRAIRIE
PERCENT FINER THAN
DEPTH INTEGRATING PARTICLE SIZE IN mm

Figure 54 Bed Material and Suspended Sediment Particle Size Distribution: Portage

1.75. About half of the samples contain sediment finer than 0.062mm and the proportion of silt/clay ranges from 0 to 42 %, although it is typically between 0 and 20%. There is also some gravel present, but there is seldom more than 10% by weight of sediment coarser than 2mm.

There is a possibility of a systematic error in bed material particle size measurement with different samplers (Ashmore et al. , 1989) but these differences are usually small for well-sorted medium sand. Any between-sampler differences in this case must also be due in part to differences in the time of sampling and, perhaps, location. Nevertheless, it is worth noting some slight differences in mean D_{50} with different samplers. Specifically, D_{50} for the four different samplers is as follows: BM-54 = 0.428 mm, BMH-53 = 0.445 mmm, Scoop = 0.453 mm, and Lane = 0.467 mm.

Since the opening of the Portage Diversion, regular surveys of the river channel downstream of the dam have included bed material sampling to check for coarsening due to channel degradation (Pickell, 1984). To date the results show no large or consistent trend in bed material particle size downstream of the Diversion except immediately downstream of the dam.

8.8 Suspended Sediment Particle Size

There is a total of 177 particle size analyses of depth- integrating samples at this station, collected between April 1956 and May 1979. The bulk of these (141) were collected prior to the opening of the Portage Diversion in 1970. Sampled discharges range from 7.5 to 657 $m^3 s^{-1}$ and sampled concentrations from 25 to 2 600 mg l^{-1}. The particle size distribution curves for these samples are shown in Figure 54. D_{50} of these samples ranges from 0.003 mm to 0.353 mm. Percent sand varies from 0 to 72%, but is typically 5 to 25% by weight.

The relationships between the particle size of suspended sediment and discharge suggest some contribution of bed material to the suspended load. Figure 55 shows that percent silt and clay decline with increasing discharge, and that the sorting coefficient and D_{50} of the sand fraction both increase with increasing discharge. D_{50} of the sand fraction at higher discharges is typically 0.2 to 0.3 mm, which is close to the D_{50} of the bed material at this station.

8.9 Point Integrating Samples

The sediment program at this site has included nine full cross-section point-integrating measurements of suspended sediment concentration and particle size. All except one (in 1976) were measured prior to 1970. Sampled discharges range from 74

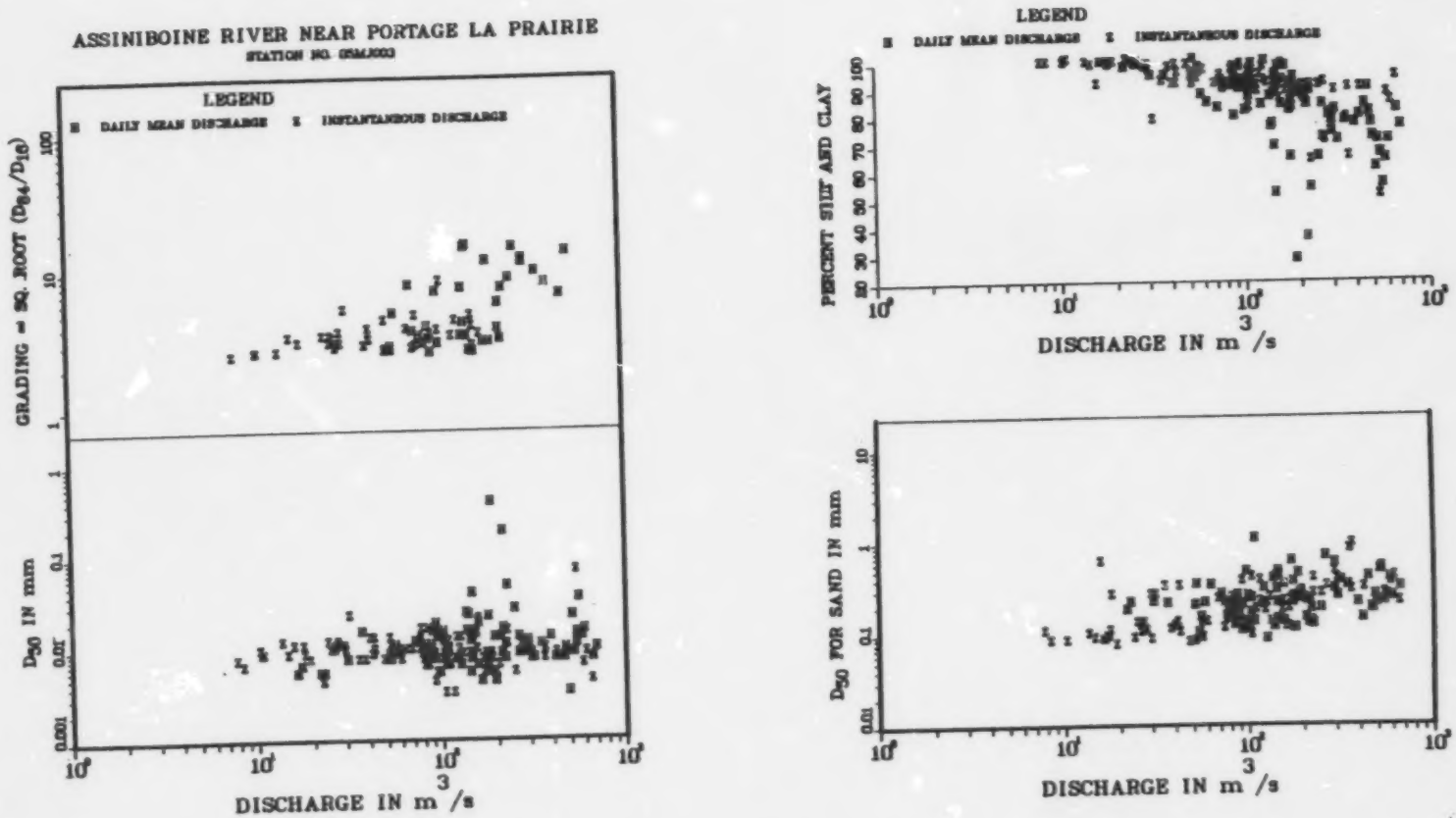


Figure 55 Suspended Sediment Particle Size Distribution Characteristics versus Discharge: Portage

to 629 $m^3 s^{-1}$ and all the measurements were made during spring freshet between mid-April and early May.

On average, for the nine samples, the maximum average concentration in a vertical is 1.45 times the minimum. This minimum concentration occurred at the right bank in 8 of the 9 samples. The lateral distribution of silt and clay shows a 15 to 20% difference between maximum and minimum, while the sand concentration varies laterally by a factor of eight.

The vertical profile of concentration for silt and clay fractions is almost uniform - concentrations near the surface average 1.02 and 0.96 of those near the bed for clay and silt respectively. In contrast, sand concentrations near the surface average 0.27 of that near the bed. The vertical gradient of suspended sediment concentration is noticeably steepest, especially for sand, at the two highest discharges at which point integrating samples were collected (April 24 1969 and April 14 1970 when discharges were 629 and 405 $m^3 s^{-1}$). It appears to be the case that only at these high discharges are significant quantities of sand entrained. This confirms that much of the sand load at high discharges is derived from the bed.

9. ASSINIBOINE RIVER AT HEADINGLEY (05MJ001)

9.1 Station Description and Sediment Program

This is the longest running sediment station in the Assiniboine basin and has a sediment record as long as any other station in the prairie provinces. Its original purpose (in 1956) was to determine the sediment load entering the Red River and passing through the City of Winnipeg. Presently its purpose (from the WSC Station Profile, 1977) is to monitor sediment loads from the entire basin and to monitor the impact of upstream flow regulation projects, channel improvement, diking and water quality. This is one of two sediment stations currently active on the main stem Assiniboine River. Program reviews in 1977 and 1979 indicated that the sediment record from this station was adequate for provincial requirements but the station has been continued to provide long term montoring for Federal purposes.

The station is located immediately downstream of the Hwy 241 bridge crossing in the village of Headingley, about 25 km upstream from the confluence with the Red River. Measurements are made from a cableway downstream of the traffic bridge (prior to 1961 measurements were taken from the bridge) and near the downstream end of a straight reach about 800 m long. The hydrometric station at this site has run continuously since 1913. The flow of the Assiniboine River at Headingley is subject to control by several regulation schemes, notably Shellmouth Dam and the Portage Diversion.

In this portion of its course the Assiniboine meanders across the Lake Agassiz plain. The river occupies a slight depression cut into the lacustrine clay and silt of the Lake Agassiz plain, and the artificial dikes that confine the river upstream near Portage la Prairie are absent. Immediately downstream of Headingley, the Assiniboine steepens and incises as it approaches the confluence with the Red River (Rannie, in press). This portion of the river is beyond the downstream limit of the Portage la Prairie 'floodplain fan' (Rannie, in press) and lateral migration of the channel is limited, although the reach upstream of Headingley shows obvious evidence of meandering activity in the form of vegetated meander lobes with scroll bars and meander cutoffs.

The sediment program at Headingley began in 1956 under PFRA direction. Until 1959 it was run on a miscellaneous basis in which sampling was limited to the spring freshet. After a hiatus in 1960, WRB began a sampling program in 1961 which sampled part of the spring peak, missed May and June and resumed in July. In 1962 sampling was continuous and has remained so until 1987 when winter sampling ceased. The sediment sampling program is quite standard. Depth-integrating samples for calculating daily concentration and load are taken at a single vertical at 75 m. Sampling frequency is flow-weighted; up to three samples per day when concentration exceeds 300 mg l^{-1}, one sample per day at medium flows and and one sample per week at low flows (concentration less than 25-30 km l^{-1}). From 1956 to 1987 there were a

total of 2 510 samples collected, of which 1 398 (56%) were collected at flows equalled or exceeded 30% of the time since 1913 (Fig. 56).

The sediment program has also included regular multiple vertical measurements for K factor calculation, full point- integrating measurements (11 in total, from 1962 to 1976), bed material particle size (62 samples, from 1962 to 1981) and particle size analysis of suspended sediment (225 analyses from 1956 to 1983, 198 of them prior to 1970).

9.2 Flow Coverage

Sampling has covered the whole flow range since 1956 and the continuous sampling has ensured coverage of the full discharge range in each year. The minimum sampled discharge is 1.13 $m^3 s^{-1}$ and the maximum sampled discharge is 614 $m^3 s^{-1}$ (1976). These are the minimum and maximum daily flows for the period 1956 to 1987 and, in the case of the maximum sampled discharge, it is the maximum daily discharge on record (Fig. 56). The adequacy of the coverage is confirmed by looking at the frequency distributions of annual maximum and annual total discharge (Fig. 57). The sediment sampling period covers the range from the highest annual maximum discharge to the third lowest, and from the second highest annual total discharge to the second lowest.

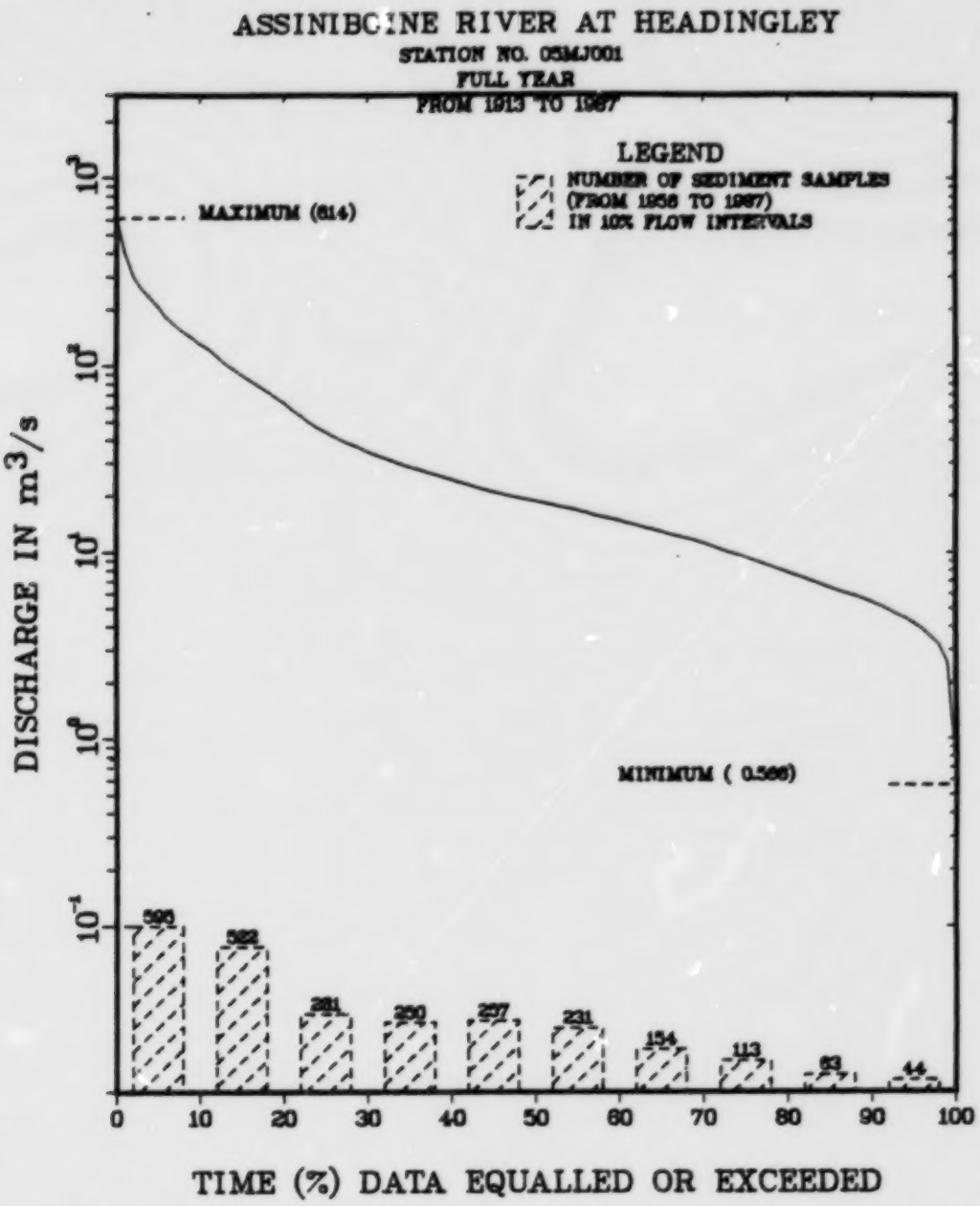


Figure 56 Frequency of Sediment Sampling: Headingley

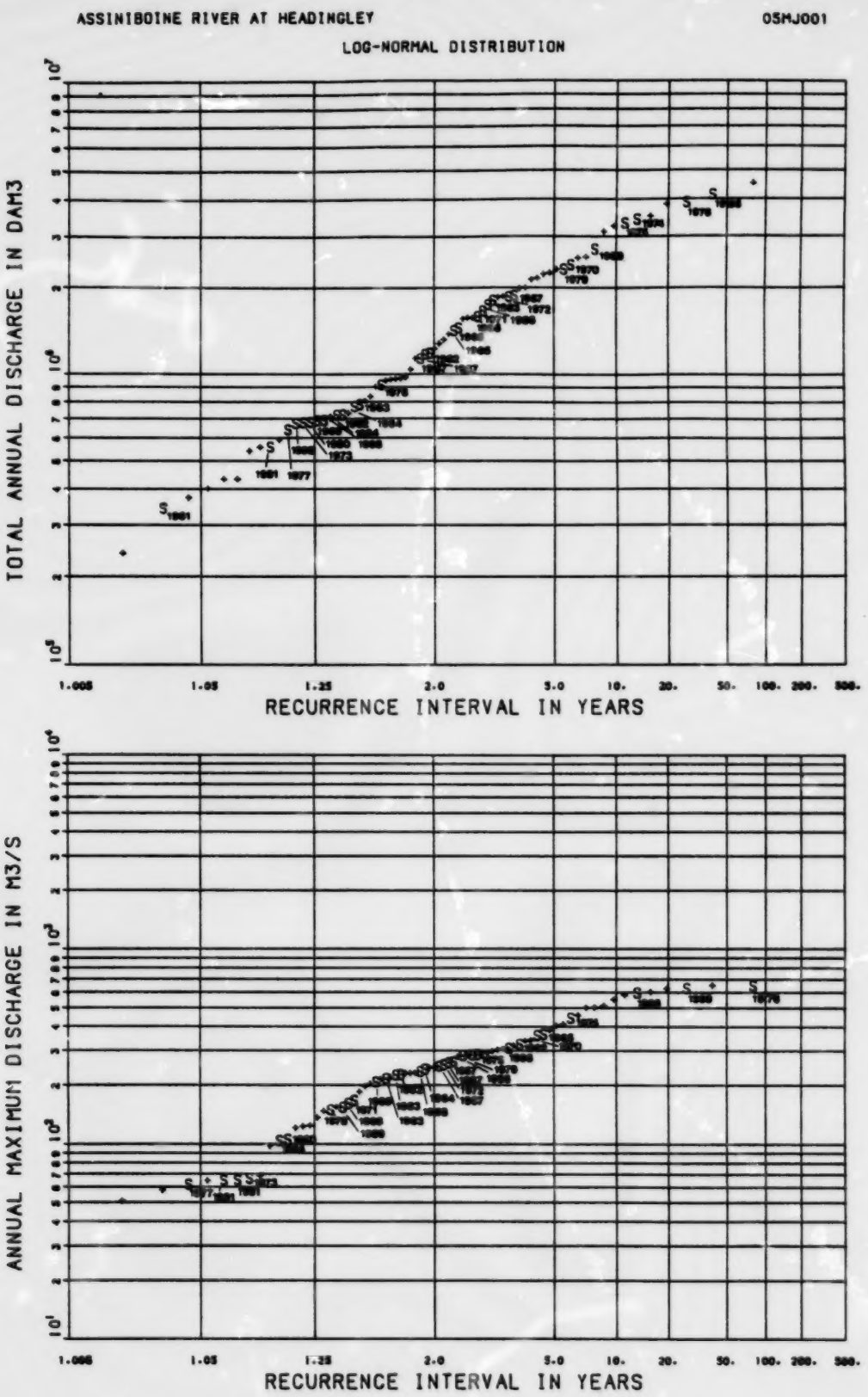
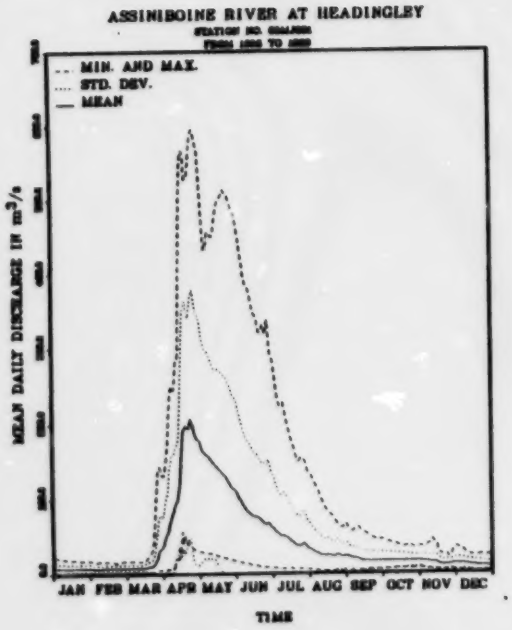


Figure 57 Coverage of Extreme Discharges: Headingley

9.3 Annual Discharge and Sediment Regime

The flow of the Assiniboine River at Headingley has been strongly regulated since 1970 by the Portage Diversion and, to a lesser extent, the Shellmouth Dam and other instream flow regulation in the upper portions of the basin. The operation of the Portage Diversion described in section 8.3 applies also to the Headingley station - the flows at Headingley are almost identical to those near Portage la Prairie. Prairie Provinces Water Board (1982) calculate that the effect of flow regulation, when compared with calculated natural flows, has been to reduce average annual discharge by about 10%, to reduce spring flood peaks and average monthly flows in April, May and June by 25 - 30%, and to augment winter flows (December to February) by 100%.

This redistribution of flow, from spring to fall and winter, is typical of the change in flow regime in the rest of the basin downstream of Shellmouth Dam, but the reduction in average annual flow is greater at Headingley than at any other station. These differences are not necessarily entirely the result of flow regulation. The changes in the measured flows at Headingley can be seen in a pre and post-1970 comparison of the annual hydrographs (Figs. 58 and 59). The most obvious change in regime can be seen during the spring when, after 1970, the rise to peak discharge is more gradual, and the peak is lower, longer and later - peak flows were consistently in late April prior to the Portage Diversion and now often do not occur until May (Fig. 59).


ASSINIBOINE RIVER AT HEADINGLEY
MIN. AND MAX.
STD. DEV.
MEAN
MEAN DAILY DISCHARGE IN m³/s
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME

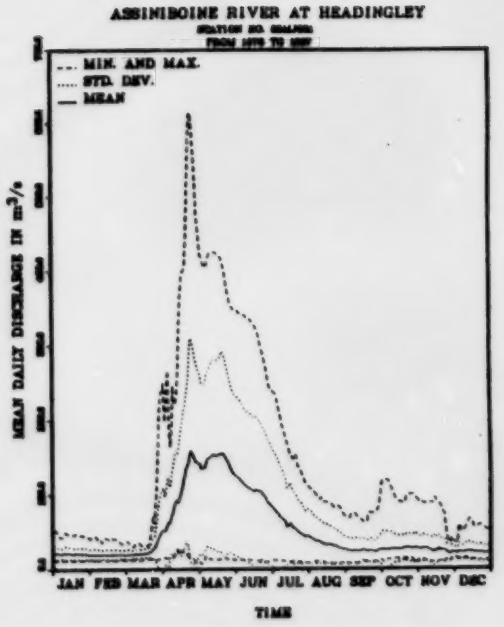
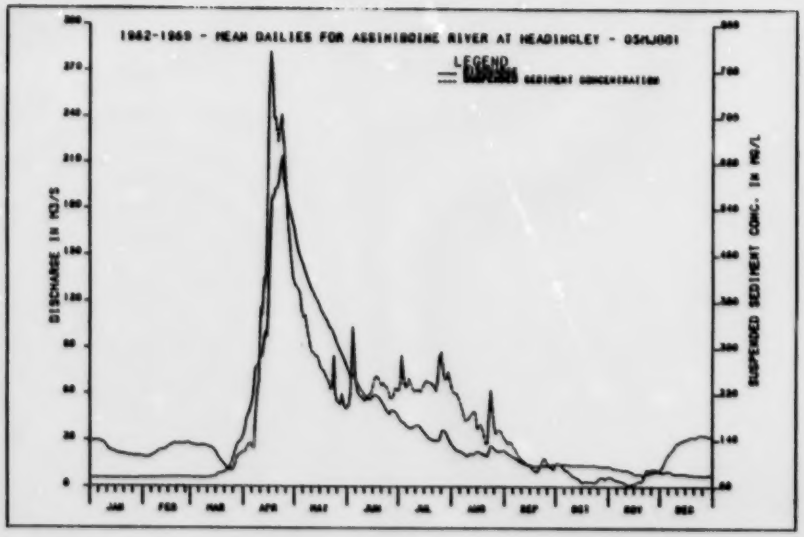
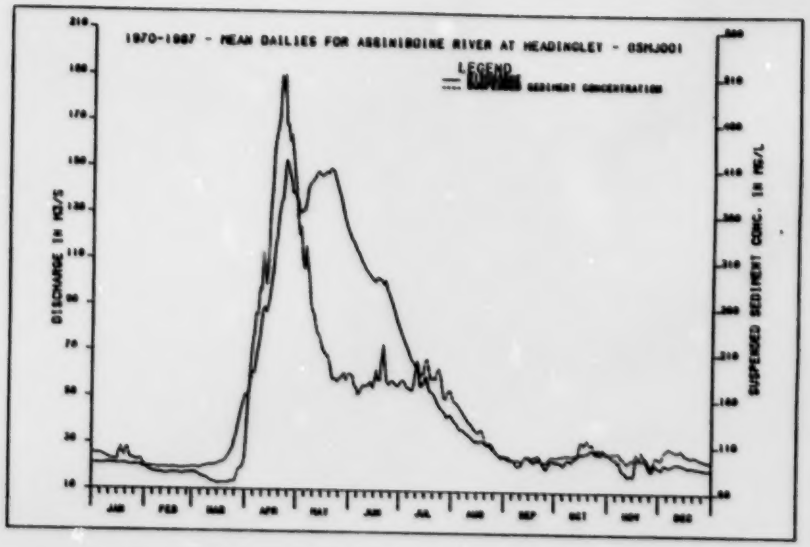

ASSINIBOINE RIVER AT HEADINGLEY
MIN. AND MAX.
STD. DEV.
MEAN
MEAN DAILY DISCHARGE IN m³/s
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME

Figure 58 Effect of the Portage Diversion on the Annual Hydrograph: Headingley


1962-1969 - MEAN DAILIES FOR ASSINIBOINE RIVER AT HEADINGLEY - 05MJ001
LEGEND
DISCHARGE IN M3/S
SUSPENDED SEDIMENT CONC. IN MG/L


1970-1987 - MEAN DAILIES FOR ASSINIBOINE RIVER AT HEADINGLEY - 05MJ001
LEGEND
DISCHARGE IN M3/S
SUSPENDED SEDIMENT CONC. IN MG/L

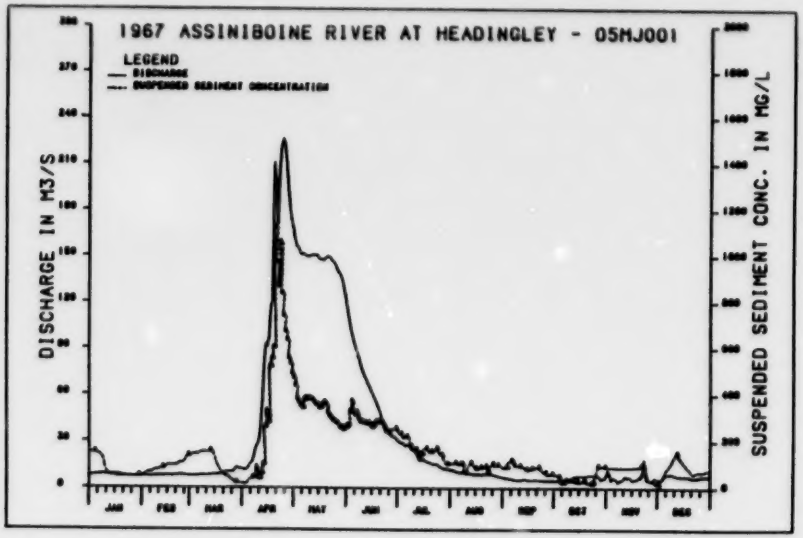
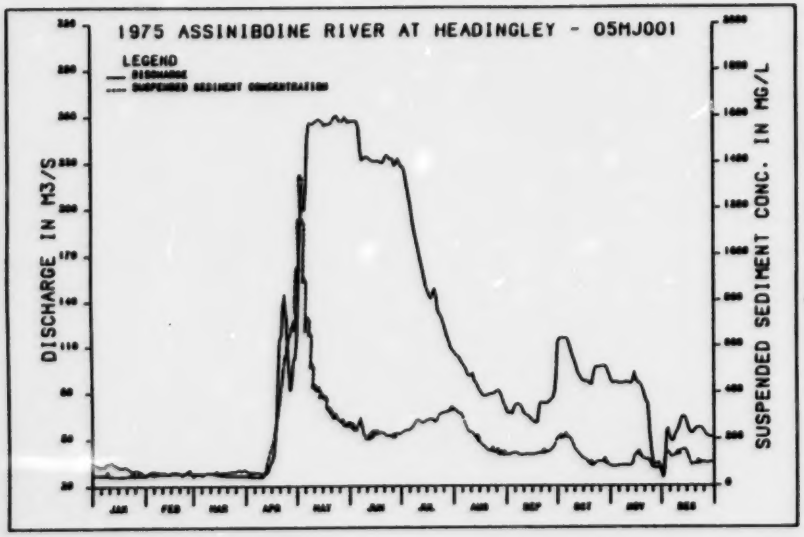
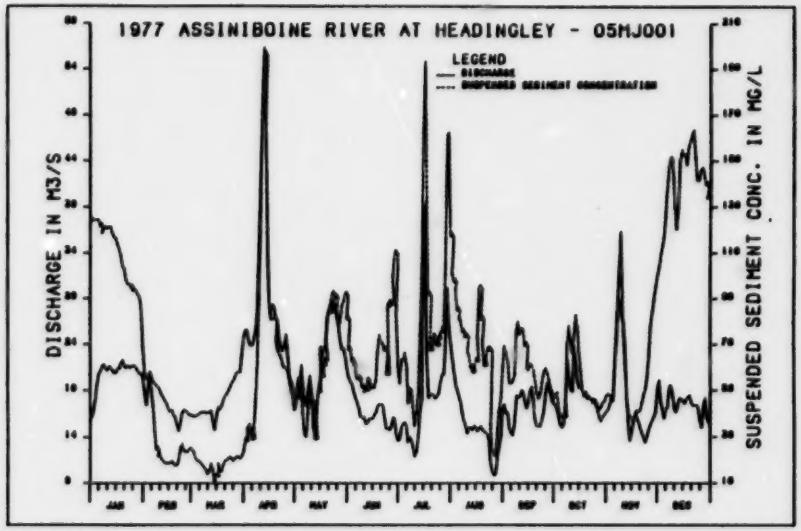


Figure 59 Examples of Annual Hydrographs and Sediment Regimes: Headingley





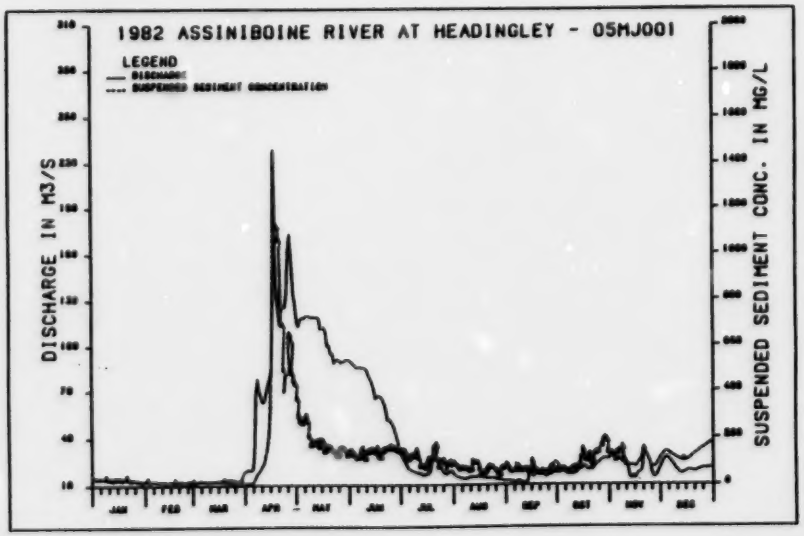


Figure 59 Continued

The effect of the change in the form of the annual hydrograph on the annual sediment regime has been, on average, to redistribute the annual load over a longer spring flood and hence to reduce the percentage of the annual load transported in April, and to enhance the relative importance of May, June and July in the transport of the annual load. In addition, the average loads during the fall and winter months have increased, but remain insignificant to the total annual load (Fig. 60). The timing of the peak sediment concentration appears to have changed little since regulation and still coincides with the discharge peak in most years, with the exception of 1970, 1972, 1975 and 1976 when the sediment peak preceded the discharge peak. These are all years in which considerable flows were diverted out of the Assiniboine River.

Peak concentrations are usually in the range 900 to 1 600 mg l^{-1} both prior to and since the opening of the Portage Diversion. After the spring peak, concentration declines rapidly to only 200-300 mg l^{-1} by mid May, and then fluctuates in response to summer runoff before levelling off at 100-200 mg l^{-1} through the winter. Individual years, especially those with low spring runoff, may deviate from this regime but it is generally true for most years of the record. In some years there is a tendency for concentrations to level off in June and July prior to their fall decline, this may be an artifact of controlled reservoir releases.

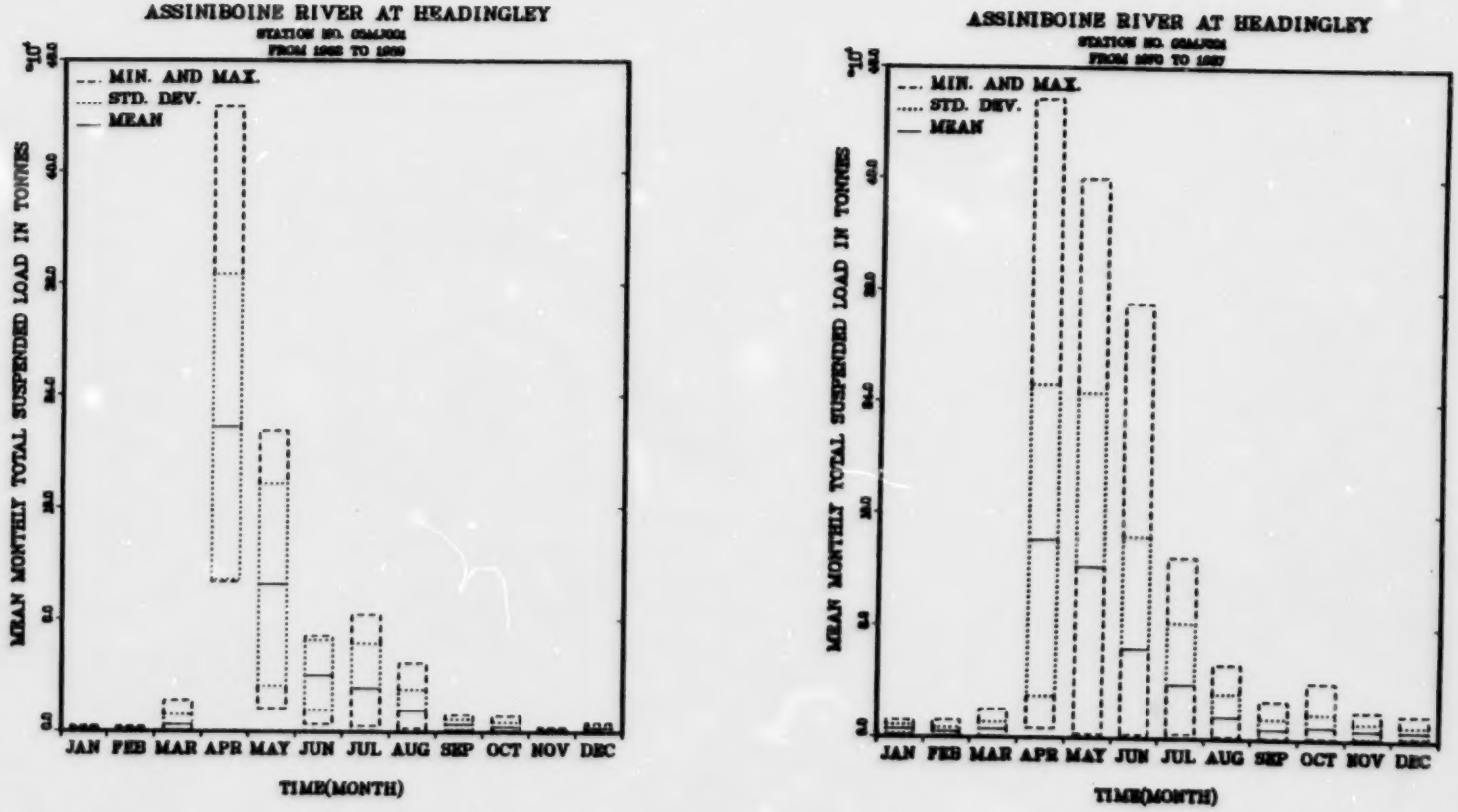

ASSINIBOINE RIVER AT HEADINGLEY
--- MIN. AND MAX.
..... STD. DEV.
— MEAN
MEAN MONTHLY TOTAL SUSPENDED LOAD IN TONNES
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME(MONTH)
ASSINIBOINE RIVER AT HEADINGLEY
--- MIN. AND MAX.
..... STD. DEV.
— MEAN
MEAN MONTHLY TOTAL SUSPENDED LOAD IN TONNES
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TIME(MONTH)

Figure 60 Effect of the Portage Diversion on the Average Monthly Sediment Load: Headingley

There is hysteresis in the relationship between suspended sediment concentration and discharge (Fig. 61). Prior to flow regulation by the Portage Diversion (1962-1969) there is a clear clockwise hysteresis in the relationship between mean monthly discharge and mean monthly load, which is most apparent during spring runoff, but includes the rising and falling stages in the winter. After 1969, the mean load and discharge of the winter months are barely distinguishable from each other, although clockwise hysteresis is still apparent during the spring flood (May - June).

9.4 Daily Mean Suspended Sediment Concentration

The annual rating curves for daily mean suspended sediment concentration versus daily mean discharge often show the hysteresis pattern discussed above in relation to monthly means. (Fig. 62). The other important feature of these concentration- discharge relationships is the change in the rating curves since flow regulation by the Portage Diversion began. The rating plots for all the sampled days in the two time periods 1956-1969 and 1970-1987 are shown in Figure 63. The regression equations for the two sets of data have almost identical slopes, but the intercept is lower for the 1970-1987 period. In fact, predicted concentrations for a given discharge are about 37% lower after 1969 than before. This compares with a reduction of about 50% at Portage la Prairie. Sediment trapping in the Portage Reservoir and diversion

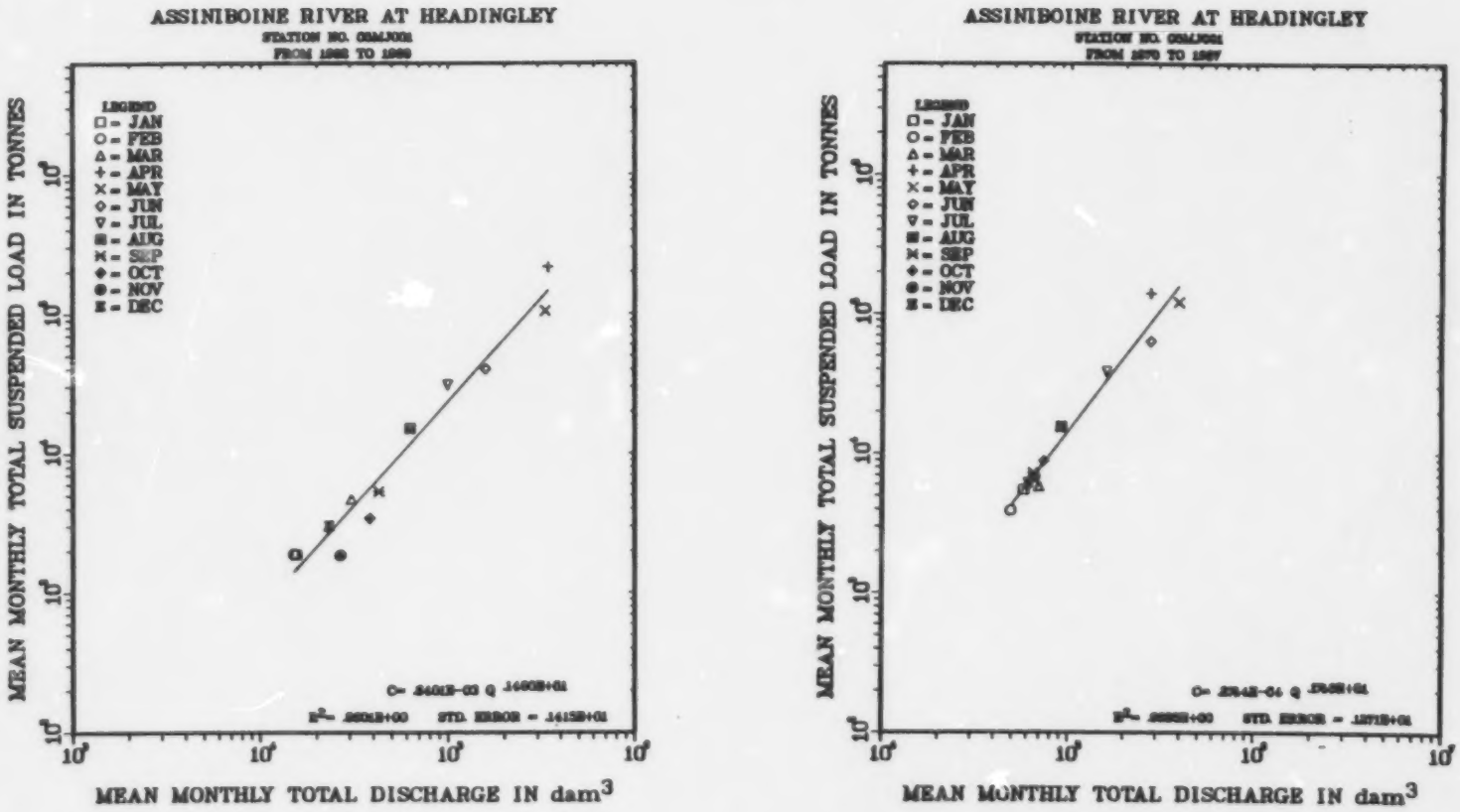


Figure 61 Mean Monthly Suspended Sediment Load versus Mean Monthly Discharge, 1962-1969 and 1970-1987: Headingley

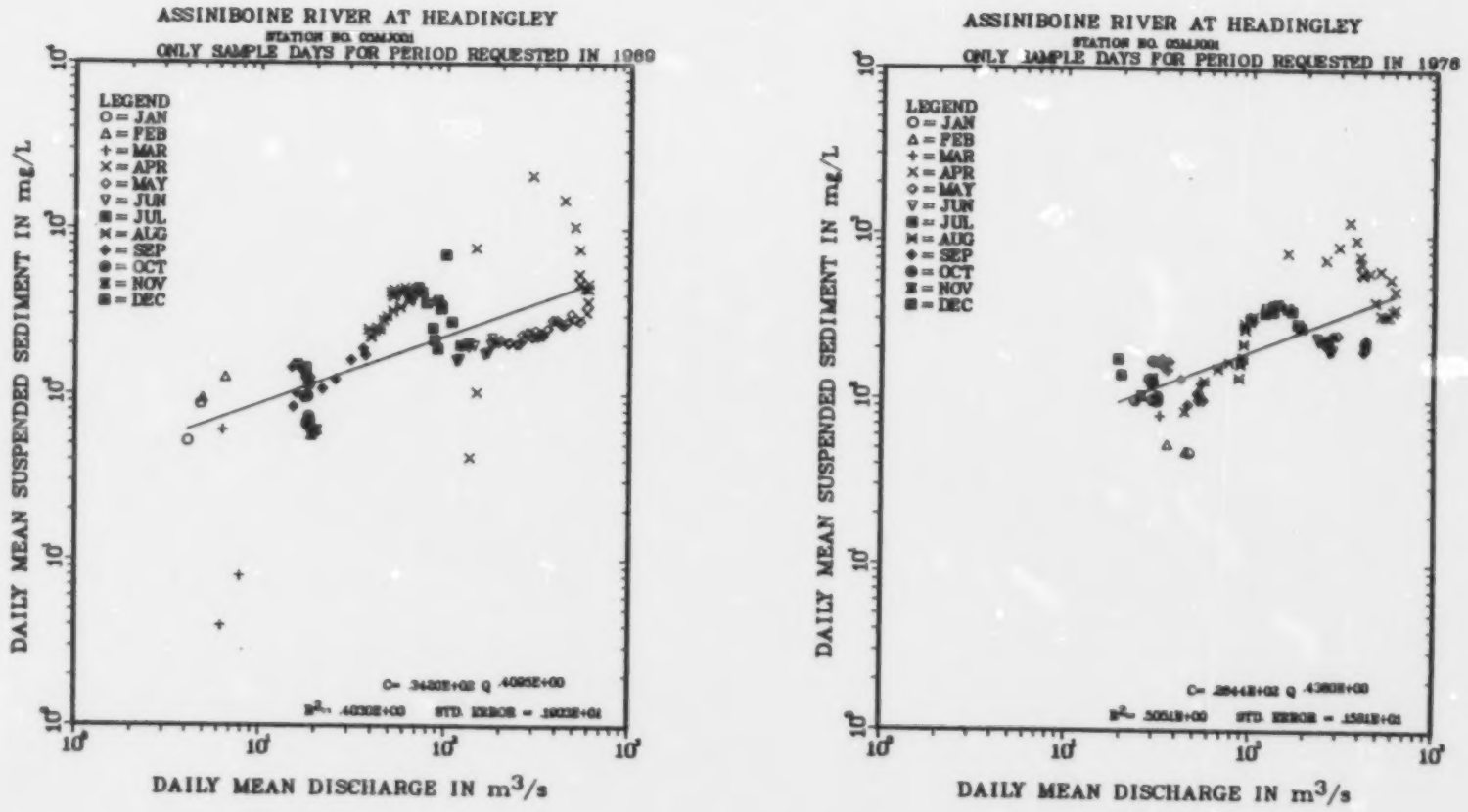


Figure 62 Examples of Daily Mean Suspended Sediment Concentration versus Daily Mean Discharge: Headingley

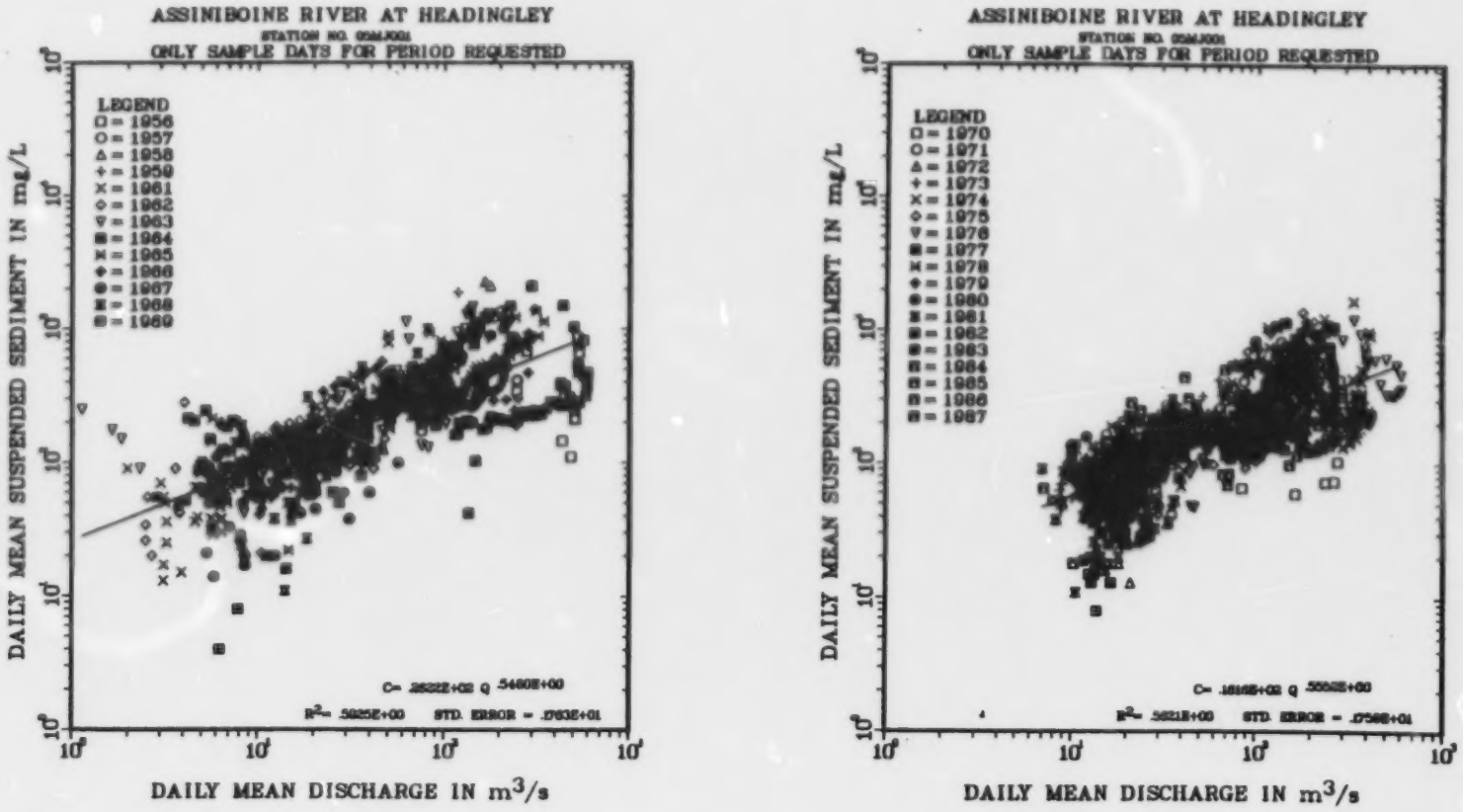


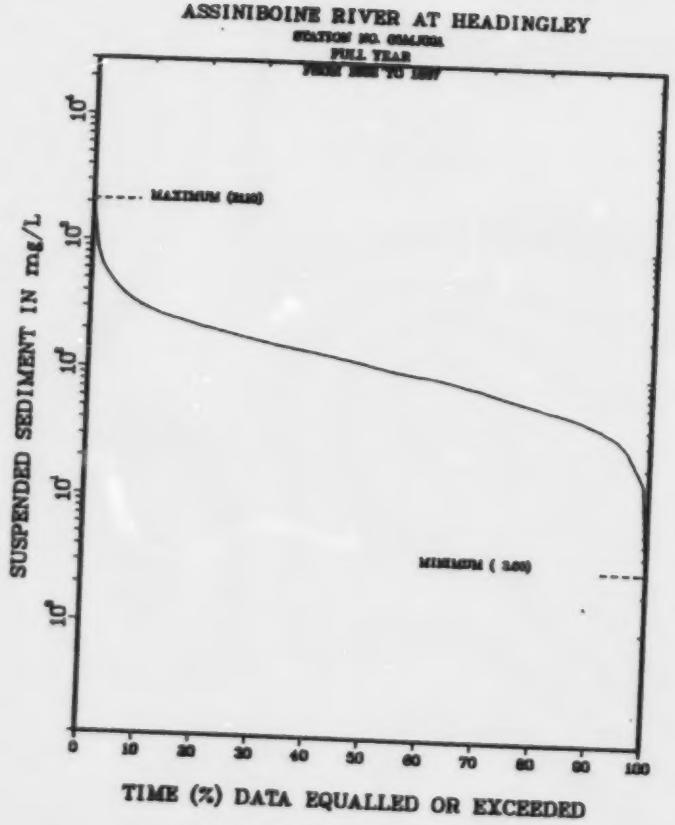
Figure 63 Effect of the Portage Diversion on the Daily Mean Suspended Sediment Concentration at Headingley

reduce concentrations at high flow, while the release of reservoir storage with low suspended sediment concentrations is responsible for reductions in concentration at low discharges.

9.5 Suspended Sediment Concentration and Load

The duration curves for daily concentration and load for the entire period of record (1956 - 1987) are shown in Figure 64. Maximum and minimum sampled concentrations are 2 500 and 3.0 mg l^{-1} respectively. Concentrations of 100 and 300 mg l^{-1} are equalled or exceeded 57% and 10% of the time respectively. Median daily concentration is 115 mg l^{-1}. The maximum and minimum daily loads are 56 900 and 1.64 Mg, the median is 182 Mg, and daily loads of 1 000 Mg are equalled or exceeded 22% of the time.

When the duration curves for the period before and after the construction of the Portage Diversion are compared, the effects of the Diversion on daily concentrations and loads become apparent (Fig. 65). Median suspended sediment concentration declined from 134 to 107 mg l^{-1} after the opening of the Diversion. At the same time the percentage of the time that concentration exceeded 300 mg l^{-1} decreased from 15 to 8%. However, median daily loads increased after the opening of the Diversion - from 117 to 204 Mg - which perhaps reflects the higher flow conditions,



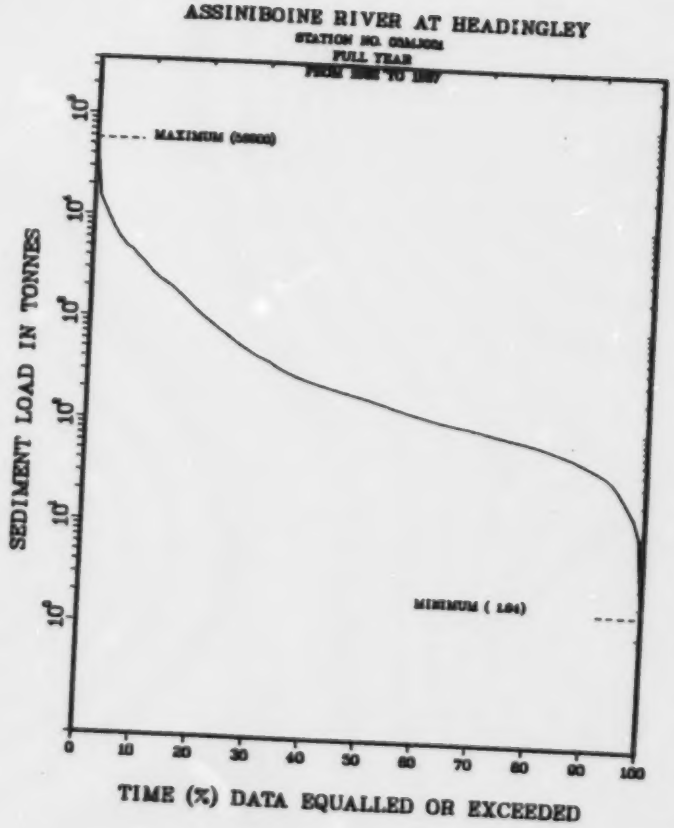


Figure 64 Daily Concentration and Load Duration Curves: Headingley, 1962-1987

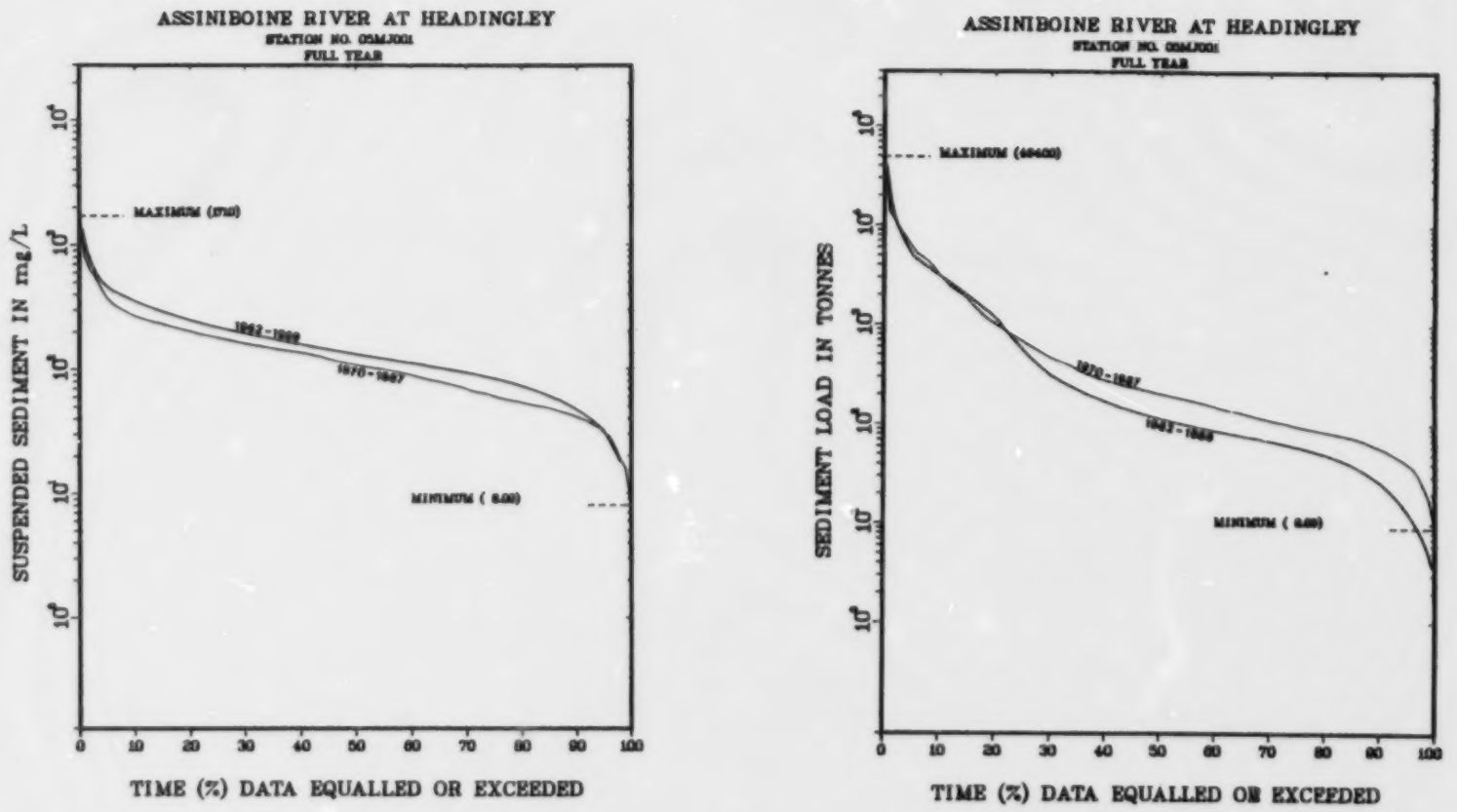


Figure 65 Effect of the Portage Diversion on the Daily Concentration and Load Duration Curves: Headingley

particularly in the mid 1970s. In contrast, the percentage of the time that daily loads of 1 000 Mg were exceeded hardly changed (from 22% to 21%).

Over the period 1956 to 1987, 80% of the load was carried in 14% of the time (Fig. 66). The discharge range transporting the largest cumulative load is 230-260 $m^3 s^{-1}$, this discharge range has a percentage exceedance of 3-4% (Fig. 66). This time distribution of suspended sediment transport has been altered by flow regulation since 1970. The cumulative load transported in a given percentage of the time is lower since the opening of the Portage Diversion than before (Fig. 67). For example, prior to the opening of the Diversion, 80% of the load was transported in 12% of the time, and after the opening of the Diversion this increased to 16%. The duration of the 'effective' discharge has decreased slightly since the opening of the Diversion (from 6 - 7% to 2 - 3%) but, perhaps more significantly, the relative importance of the extreme discharges to the long term sediment load has been considerably reduced (Fig. 68).

On average, 55% of the annual load is transported by the maximum 37 day load and 16% by the maximum 3 day load (Fig. 69). This time distribution of sediment load has also been affected by the flow regulation schemes. The average maximum 37 and 3 day loads are 68% and 22% of the annual load prior to regulation, but have been reduced to 50% and 13% since regulation. Therefore, the load is more evenly

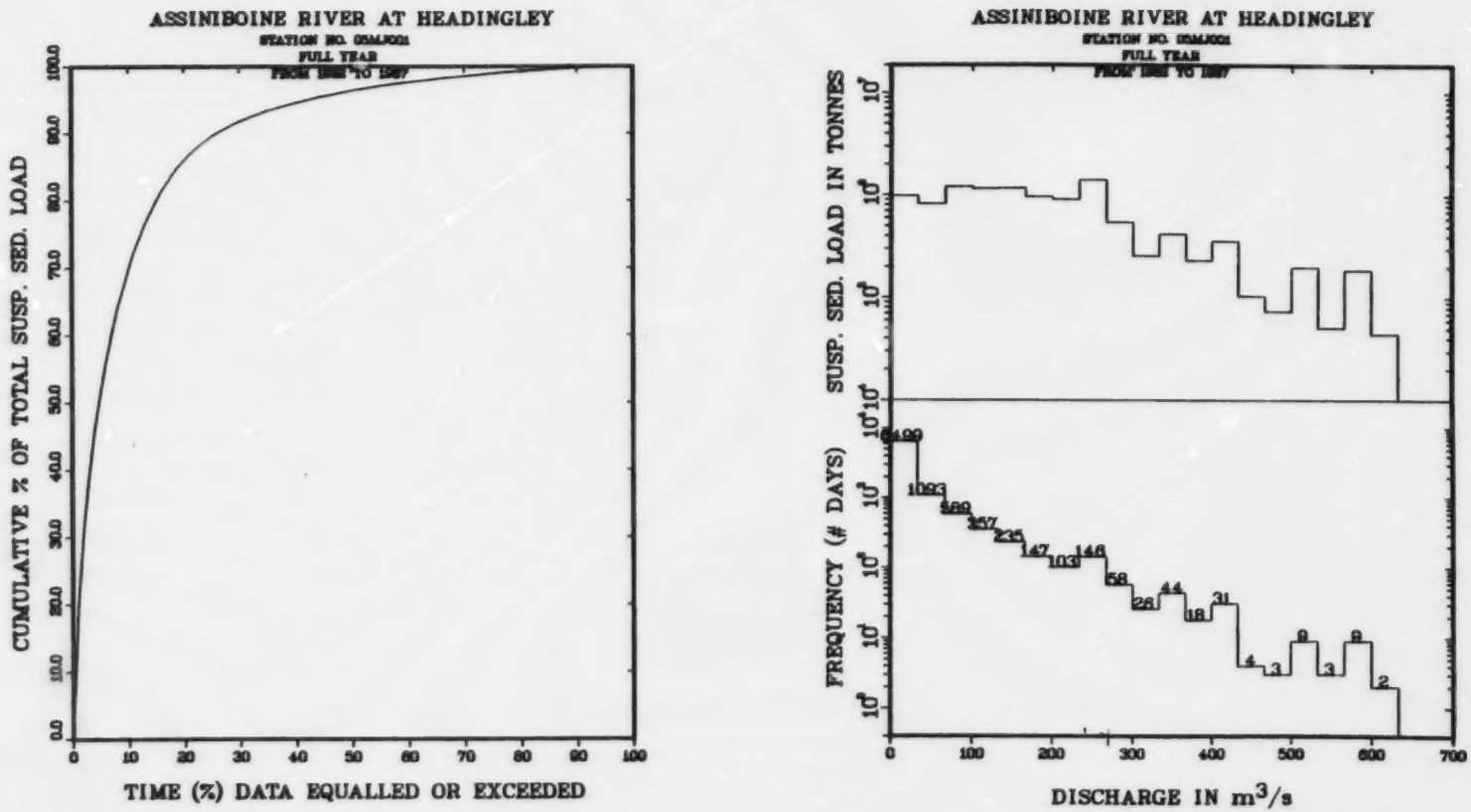


Figure 66 'Effective' Discharge Diagram and Cumulative Load Duration Curve: Headingley, 1962-1987

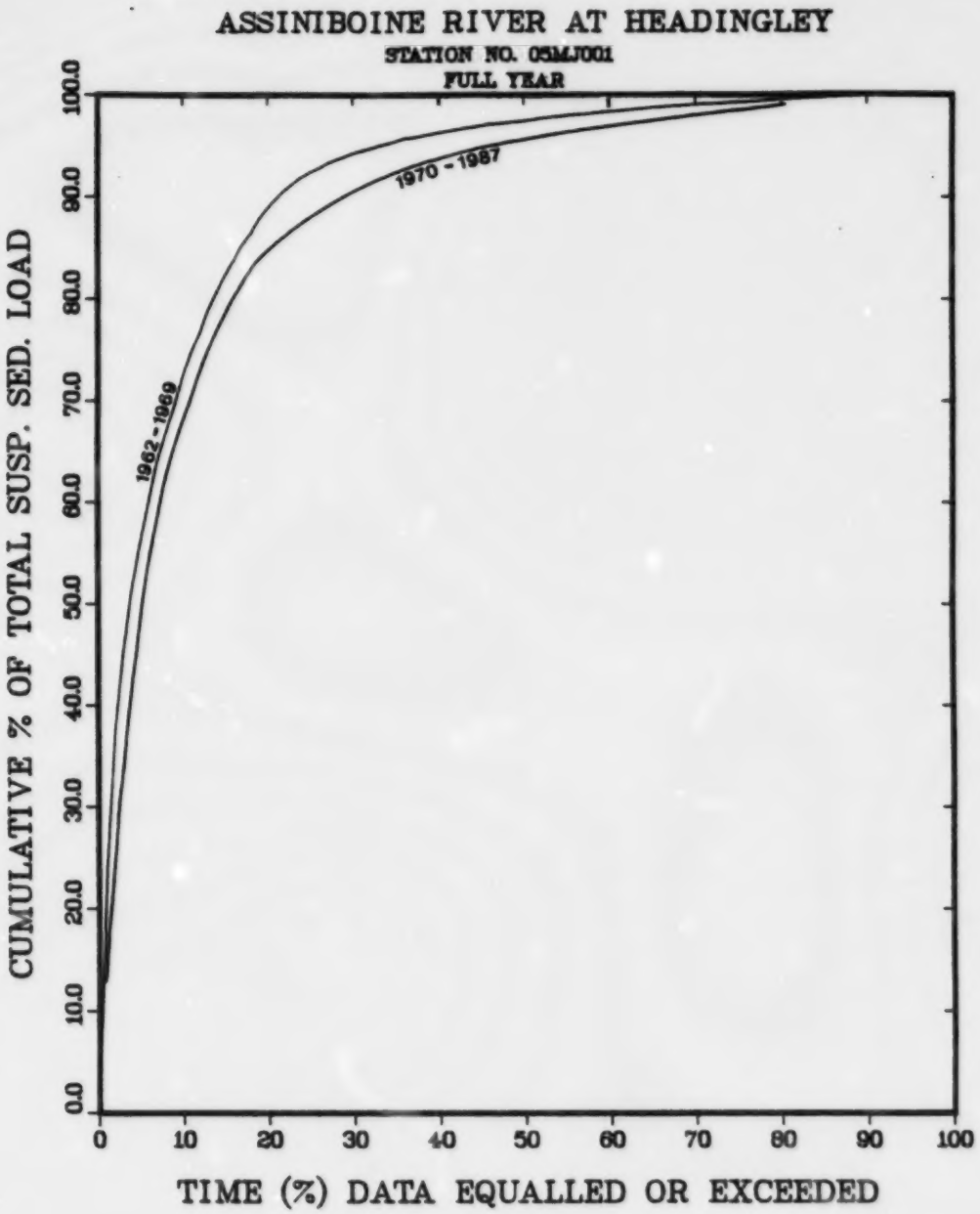
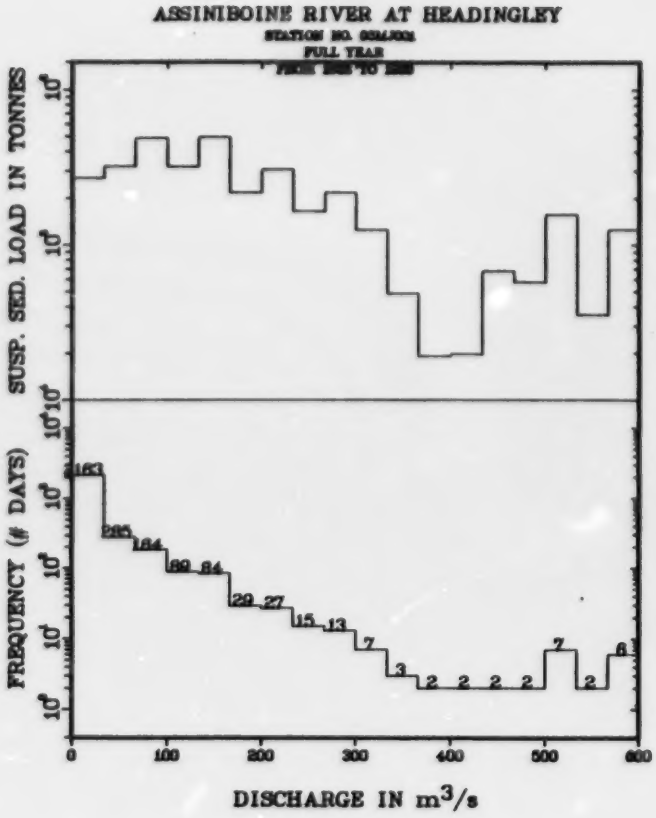


Figure 67 Effect of the Portage Diversion on the Cumulative Load Duration Curve: Headingley



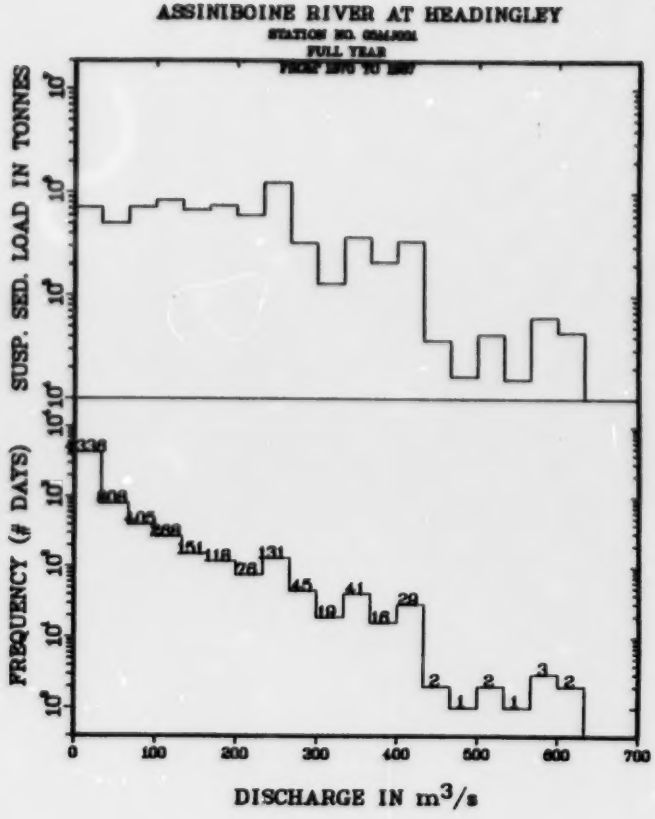


Figure 68 Effect of the Portage Diversion on the 'Effective' Discharge Diagram: Headingley

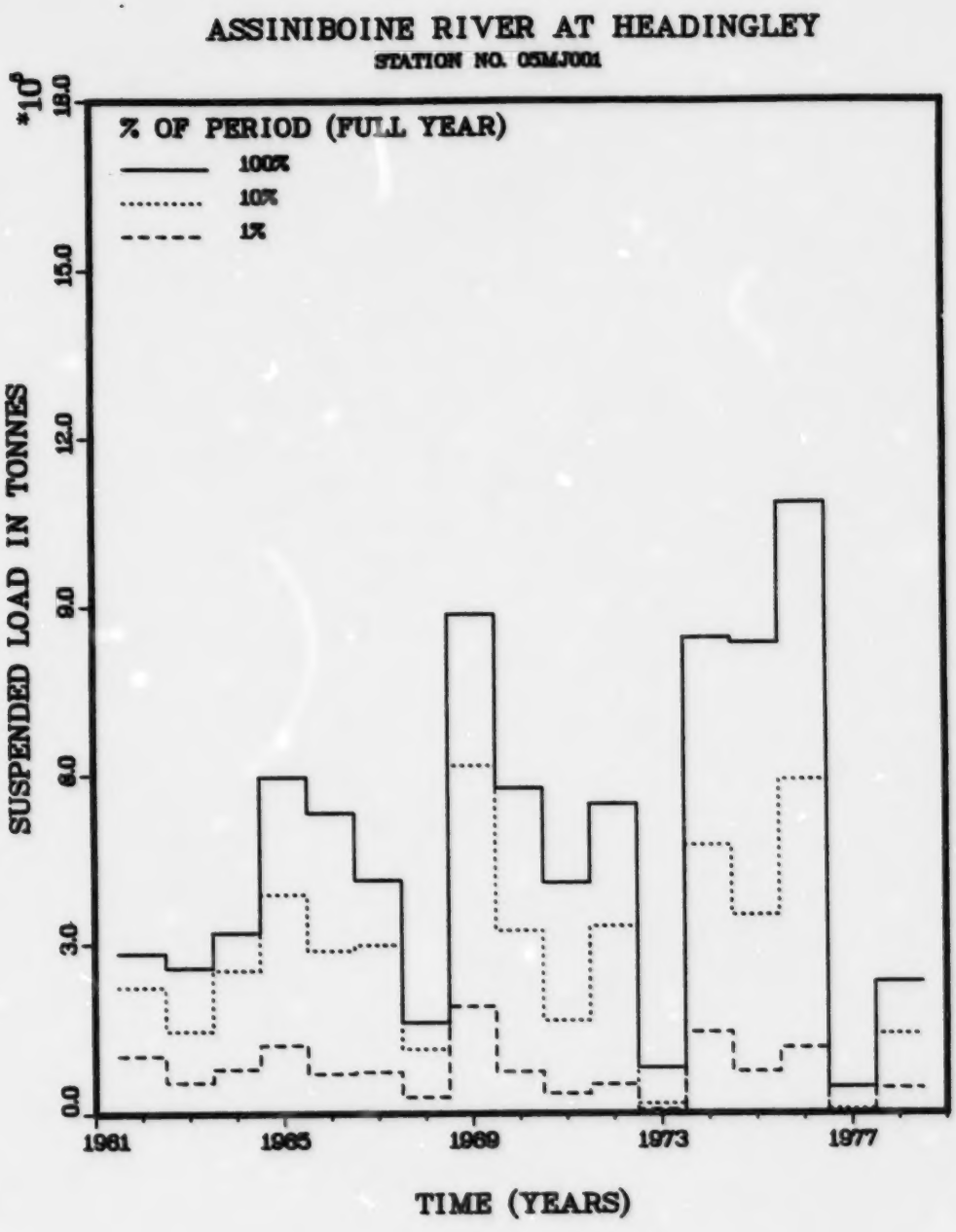


Figure 69 'Best Percent' of the Annual Load

distributed over the year and the peak flows transport a lower proportion of the load than prior to flow regulation.

9.6 Total Annual Sediment Load and Yield

The mean annual load of the Assiniboine River at Headingley between 1962 and 1986 is 434 000 Mg, with a standard deviation of 306 000 Mg and standard error of the estimate of the mean of 14.1%. Annual loads range from 35 650 Mg in 1981 to 1 085 000 Mg in 1976. The highest four years (1969, 1975, 1976, 1979) account for 35 % of the 25 year cumulative load (see Fig. 69). The standard error of the estimate appears to have stabilized (Fig. 70) and an increase in the length of record will do little to reduce the error in the estimate. The mean annual ratio of load to total flow is 286 mg l^{-1}.

The Portage Diversion has clearly influenced the annual load of the Assiniboine River at Headingley. Mean annual load is little different before and after 1969 (mean annual load, 1962-1969 = 431 000 Mg and 1970-1986 = 435 000 Mg), but this is largely a reflection of the higher annual flows after 1970 than the absence of influence of the Portage Diversion. The ratio of mean annual load to mean annual flow has declined from 360 to 263 mg l^{-1} after 1969. This is apparent in Figure 71, a plot of mean annual concentration versus mean annual discharge, in which the years prior to 1970 plot consistently above the regression line. The plot of cumulative load versus

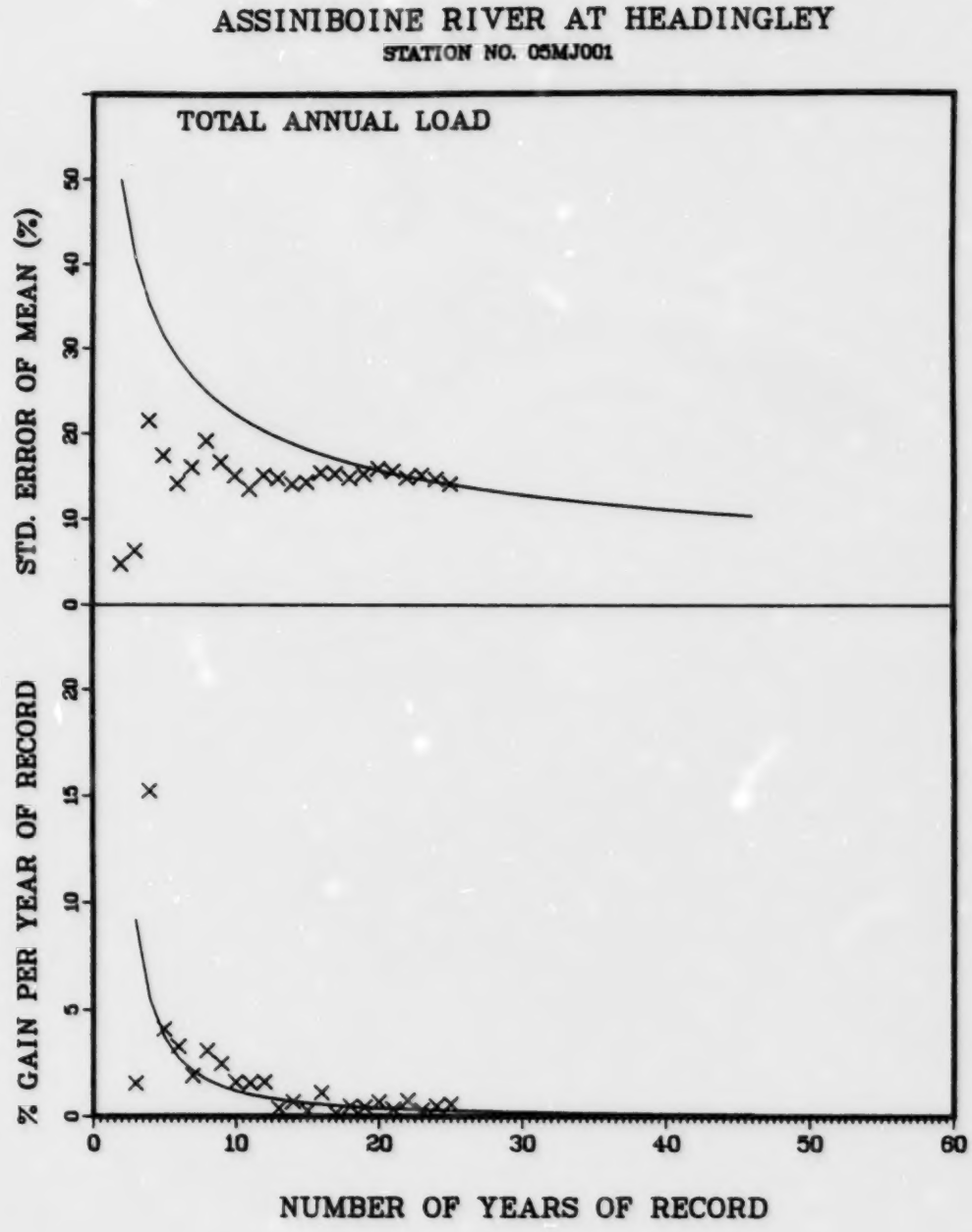


Figure 70 Standard Error of the Annual Load

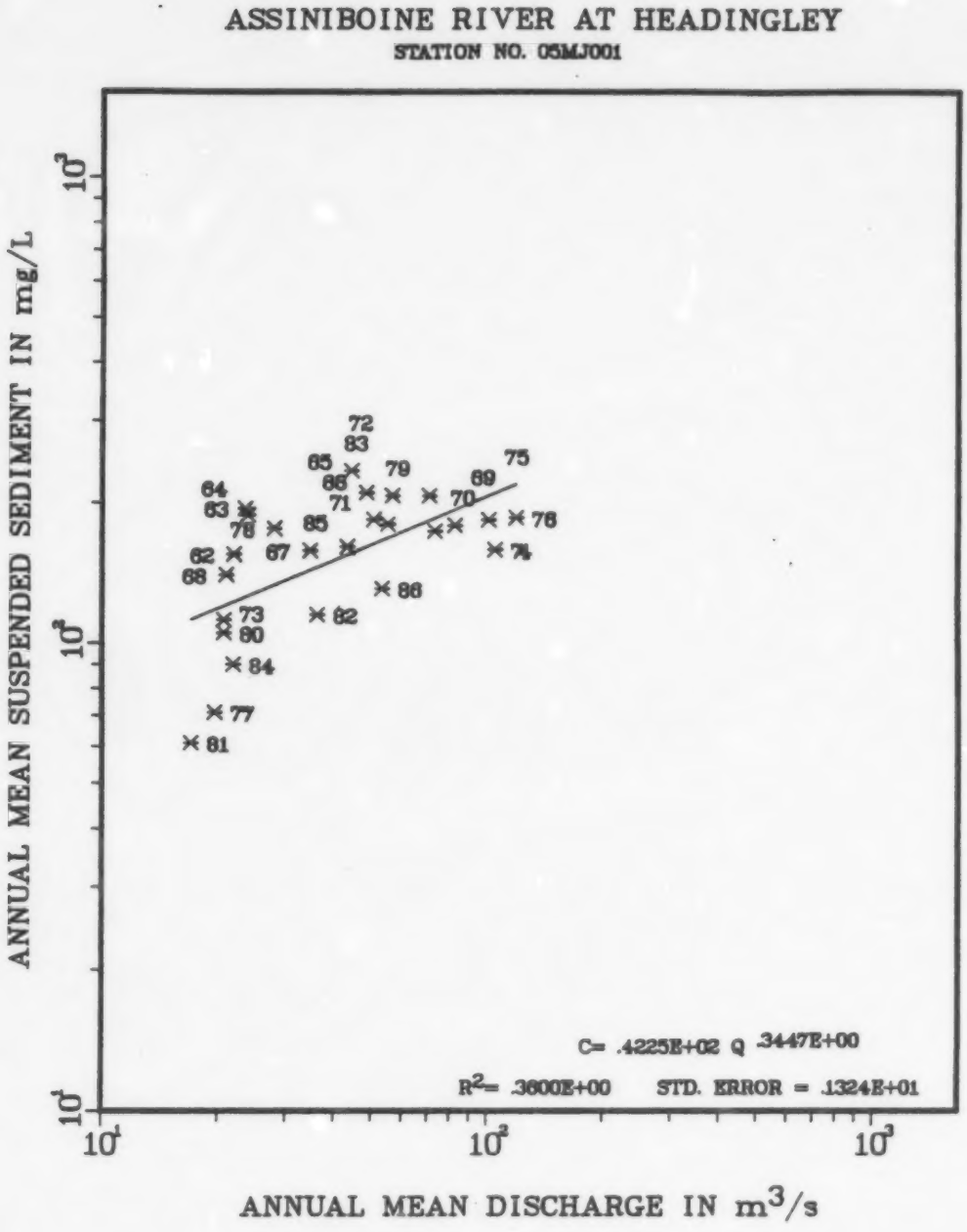


Figure 71 Annual Mean Suspended Sediment Concentration versus Annual Mean Discharge: Headingley

cumulative discharge (Fig. 72) shows a break in slope after 1969, which implies a lower rate of increase in cumulative load for the same rate of increase of cumulative discharge.

The length of the flow record at Headingley allows the period of sediment record for all the stations in the basin to be put in context of the historical flows (Fig. 73). The post Portage Diversion flows have not been adjusted for the discharge lost through the Diversion. In the context of the flow record since 1913, the period 1956 to 1968 was one of consistently below average total annual flow, from 1970 to 1976 flow was generally above average and since then mean annual total flow has been below average in most years. This suggests that the stations at Headingley, Portage la Prairie, and Holland may give reasonable estimates of the long term load, but those at Russell and Kamsack may be overestimates because they were measured during a period (1969 to 1979) of above average annual flows. When comparing loads and yields downstream through the basin this fact needs to be considered.

9.7 Bed Material Particle Size

The particle size distribution for the 62 bed material samples collected at this site between 1956 and 1981 are shown in Figure 74). The samples were collected with four different samplers - BM-54 (25 samples), BMH-53 (21 samples), Scoop (6

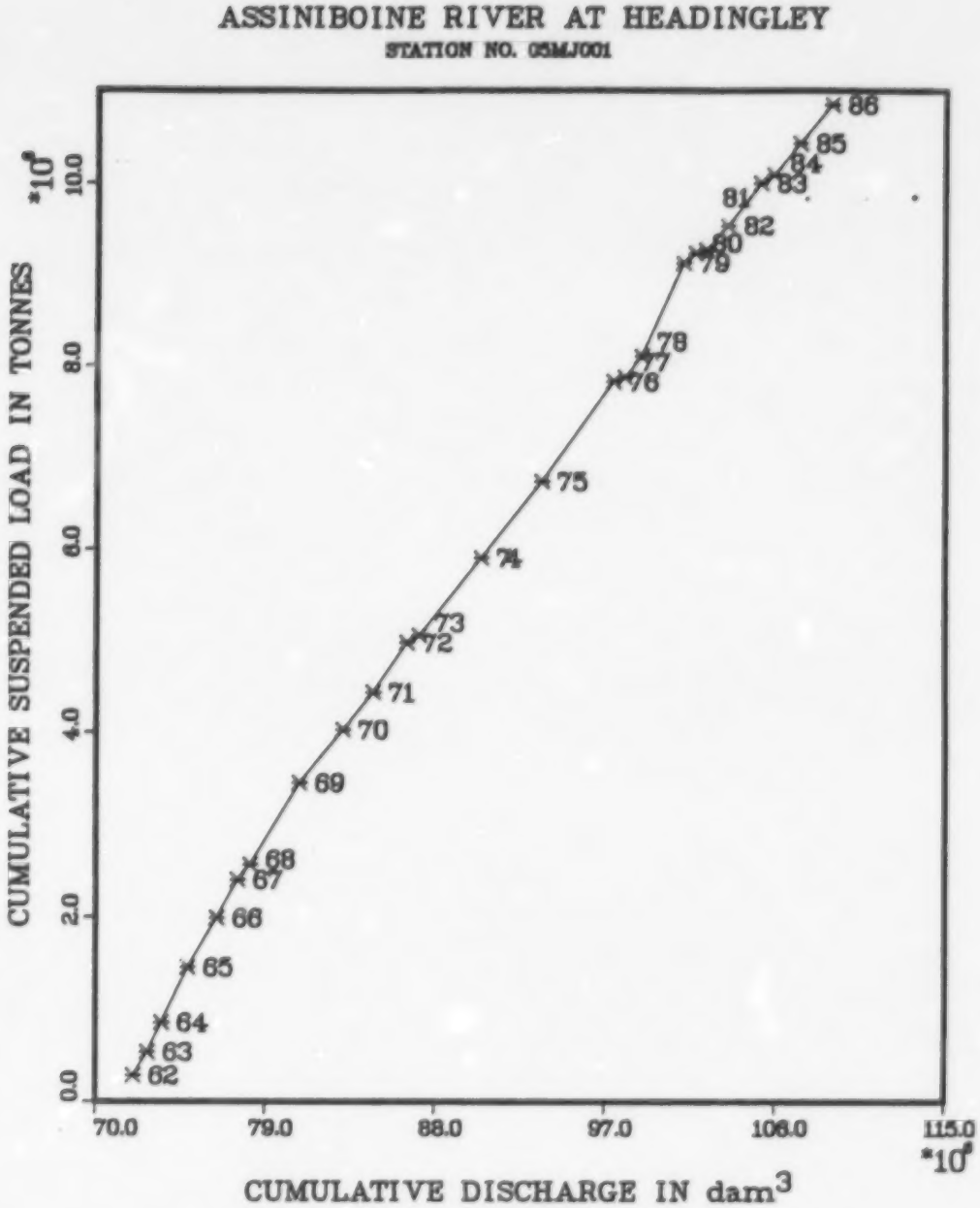


Figure 72 Cumulative Suspended Sediment Load versus Cumulative Discharge: Headingley

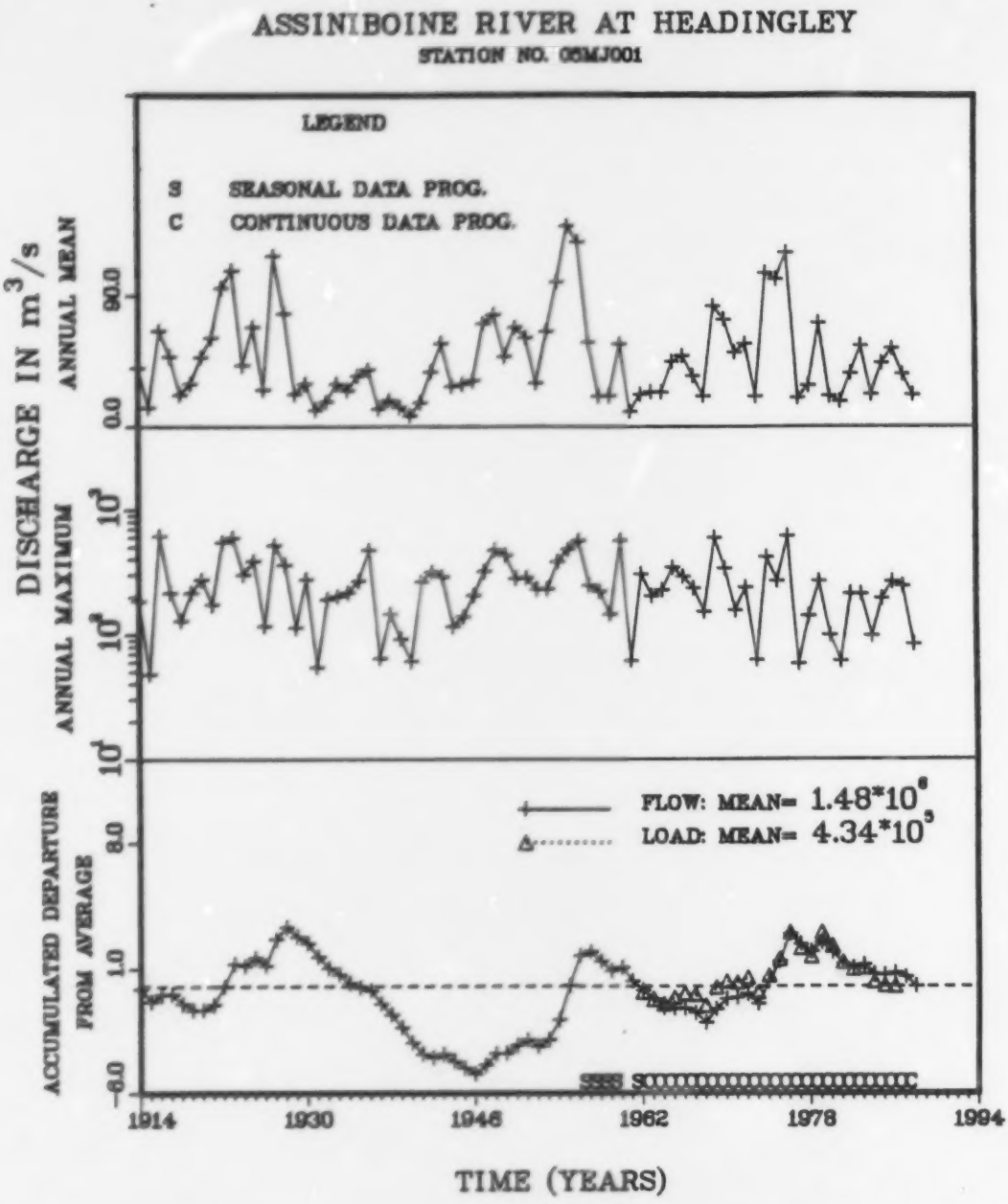
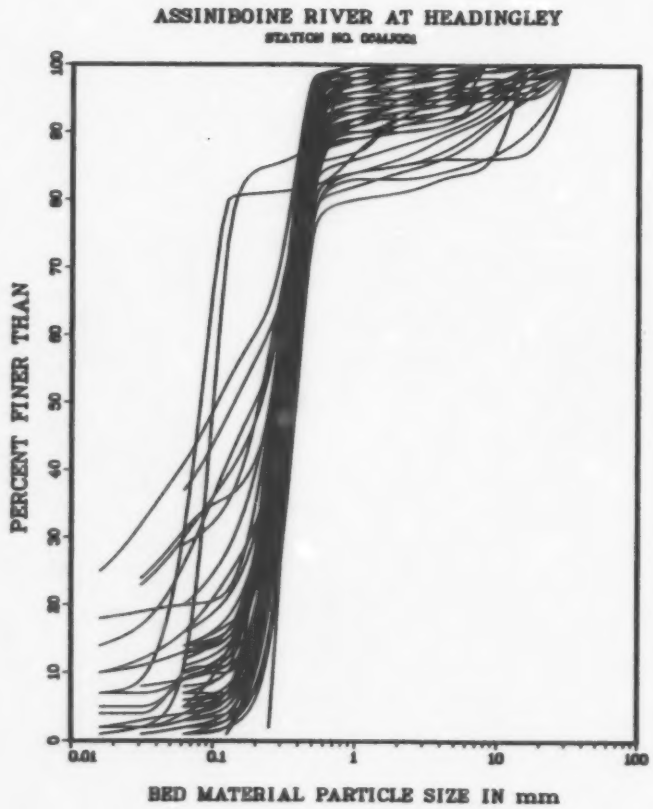


Figure 73 Flow History, 1913-1987: Headingley



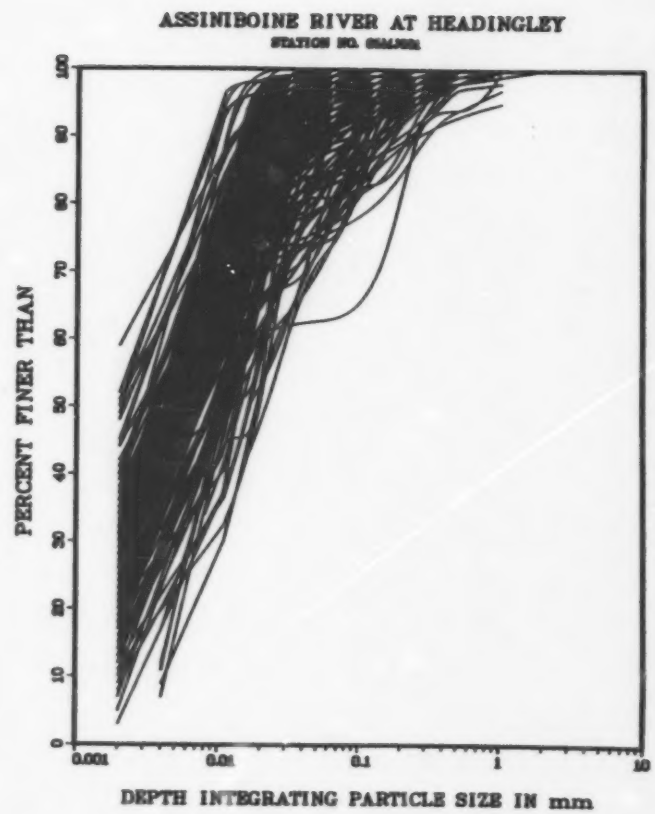


Figure 74 Bed Material and Suspended Sediment Particle Size: Headingley

samples) and Lane (5 samples), there are four samples for which the sampler type is not identified. Each sample consists of the combined results from several verticals, usually five. Mean D_{50} is 0.306 mm and ranges from 0.099 to 0.381 mm. Almost all the samples contain a significant component finer than 0.062 mm, and this is as high as 41%, although it averages about 10%.

When segregated by sampler type, slight differences in the estimation of D_{50} are apparent. In particular, the D_{50} from the BM-54 samples is 0.292 mm compared with 0.322 mm from the BMH-53. This discrepancy is not necessarily due to bias in the samplers but it is expected considering the results of Ashmore et al. (1989) on sampler bias. The bed material consists mainly of well-sorted, medium-fine sand, but in all cases there is some gravel present, although usually less than 10%, and often less than 5%, by weight.

9.8 Suspended Sediment Particle Size

There are 225 particle size analyses of suspended sediment samples at this station, collected between 1956 and 1983 (Fig. 74). 198 of these were collected before 1970. These samples were collected at discharges ranging from 8.3 to 610 $m^3 s^{-1}$ and concentrations ranging from 26 to 2 260 mg l^{-1}. D_{50} ranges from 0.0020 to 0.021 mm, but is typically 0.005 to 0.010 mm. At discharges over 10 $m^3 s^{-1}$ there is a sharp decrease in percent silt/clay in the suspended load, and a corresponding increase in

D_{50} of the sand fraction, such that at higher discharges D_{50} of the sand fraction is often about 0.2 mm - within the range of the D_{50} of the bed material (Fig. 75).

9.9 Point Integrating Samples

The sediment program at this site has included 11 full point-integrating measurements of cross-section variation in concentration. The most recent measurement is April 15, 1976, the remainder were taken one per year (except 1964 when there were 2) from 1962 to 1970. Samples were taken in April or May of these years at discharges up to 436 $m^3 s^{-1}$.

Lateral variability in concentration is lower here than at any other station on the Assiniboine River, primarily because of the proportionally lower sand transport at this site. On average, there is about a 20% difference between the maximum and minimum average concentrations between verticals. This lateral variability is typical of the silt and clay fraction also. The variability for the sand fraction is considerably greater - the largest concentrations are 3 or 4 times greater than the smaller.

Because the sand fraction is a significant component of the load in only two or three samples (in the remainder it comprises less than 10% of the load and concentrations are generally less than 100 mg l^{-1}), the vertical distribution of supsended sediment is fairly uniform. Concentrations near the surface average about 90% of those near the bed. The silt and clay concentrations show no significant vertical

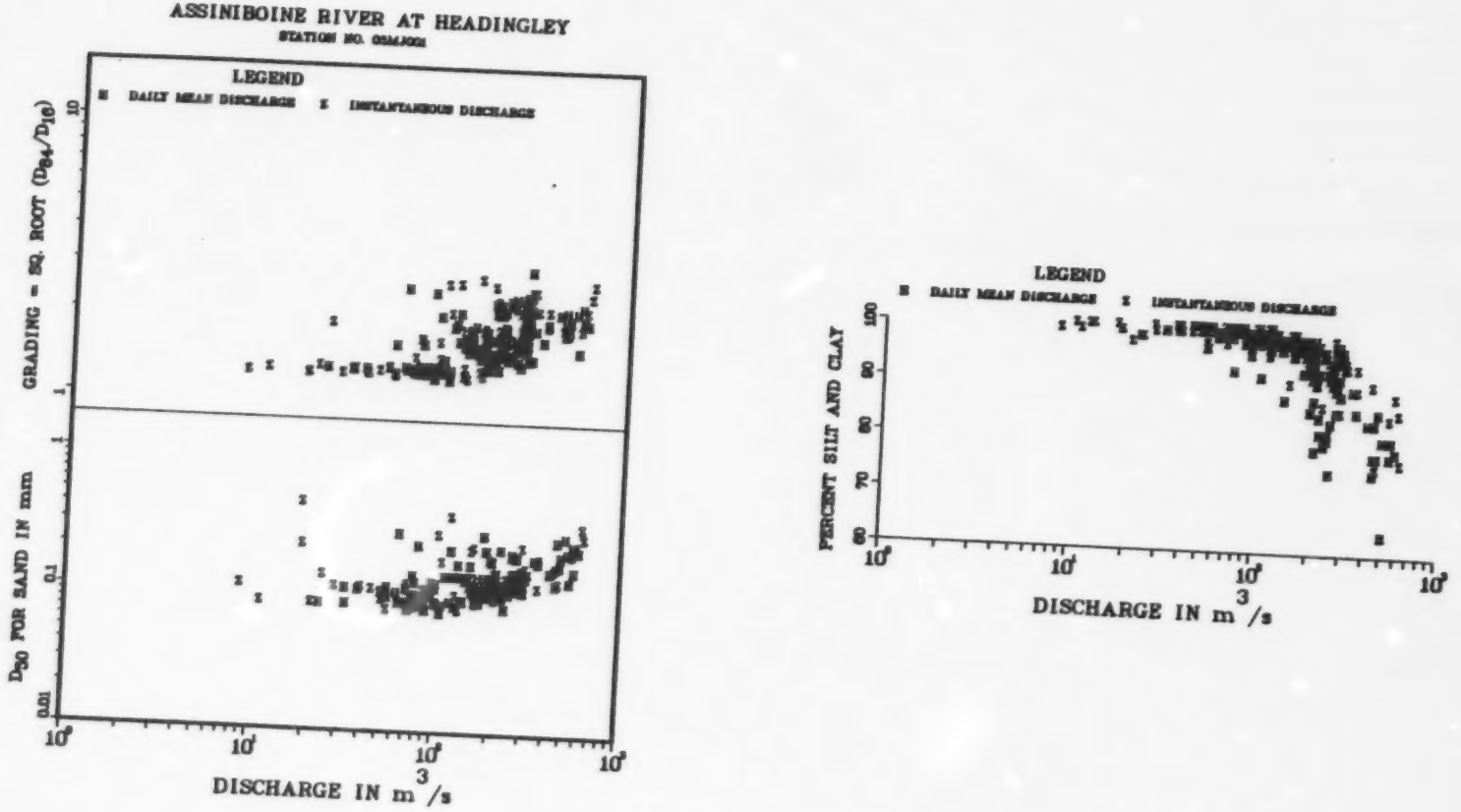


Figure 75 Suspended Sediment Particle Size Characteristics versus Discharge: Headingley

variation in concentration at all. Only at high discharges, when the coarser sandy bed material is mobilized, is there a noticeable vertical gradient of suspended sediment concentration.

10. WATER QUALITY SEDIMENT DATA

Water Quality Branch (WQB), Environment Canada, and Manitoba Department of Environment conduct analyses of the concentration of suspended sediment in routine water analyses. These are referred to as 'nonfilterable residue'. The sampling schemes used by WQB and Manitoba Environment are not designed to compute loads, and for the most part they are collected either occasionally for specific studies, or regularly about once per month without regard to the discharge. Thus, these data can provide only an indication of the concentrations of suspended sediment, and may not cover the range of flows at a particular station. In addition, few of the water quality stations coincide with WRB sediment stations and therefore direct comparisons between the two are not possible.

Water quality data are available for 11 Federal and 27 Provincial stations along the Assiniboine River. They are summarized in Tables 4 and 5. These data give a general impression of increasing average concentration downstream, which matches the pattern from the WRB sediment stations. For example, the Provincial data show maximum concentrations increasing downstream from 30 mg l^{-1}, to about 400-500 mg l^{-1} at Brandon and about 1000 mg l^{-1} at Holland, Portage and Headingley. However, it is difficult to make detailed comparisons of any validity. The water quality stations that coincide with WRB sediment stations tend to give ranges of concentration comparable with those from the sediment stations, but the WRB sediment station data provide a

TABLE 4 Summary of Water Quality Branch NFR Data for Assiniboine River

Station name	Station no.	Sampling Period	No. of Samples	Concentration (mg l^{-1}) Max.	Min.
Assiniboine R. above Whitesand R.	SA05MC0001	8/1968-3/1974	15	93	4
Assiniboine R. at Kamsack	SA05MD0001	12/1966-2/1974	13	74	2
Assiniboine R. at Hwy. 8 below Kamsack	SA05MD0002	8/1968-present	188	154	1
Assiniboine R. west of Russell at Hwy. 4	MA05ME0001	1961-1974	11	53	1
Assiniboine River near Rivers Camp	MA05MG0001	1962-1974	16	294	2
Assiniboine River at Brandon	MA05MH0001	1961-1978	26	220	5
Assiniboine R. above Souris R. at Treesbank	MA05MH0003	1/1973-3/1975	48	179	1
Assiniboine R. above Portage la Prairie at Fort la Reine	MA05MJ0035	1/1973-3/1975	57	607	6
Assiniboine R. at Portage	MA05MJ0001	1961-1974	26	1 268	2
Assiniboine R. nr. Headingley	MA05MJ0006	1989	3	234	71
Assiniboine R. at Hwy. 100 nr. Charleswood	MA05MJ0017	1971-1989	4	329	24

TABLE 5 Summary of N.F.R. Data from Provincial Water Quality Stations on Assiniboine River.

Station Location	Station No.	Sampling Period	No. of Samples	Concentration (mg l^{-1}) Max.	Mean	Min.
Sask. PR #369 south of Togo	WQ0001	6/1973-10/1977	26	30	12	5
Below spillway Shellmouth Dam	WQ0002	3/1973-10/1977	27	30	10	5
PR #478 W. of Binscarth	WQ0003	5/1973-10/1977	26	140	34	5
PTH #41 W. of St. Lazare	WQ0004	8/1969-10/1977	57	300	48	5
PTH #83 S. of Miniota	WQ0005	7/1965-3/1984	136	320	63	5
PR #259 N.E. of Virden	WQ0006	7/1965-10/1977	62	250	69	9
PR #257 E. of Virden	WQ0007	7/1965-10/1977	60	360	74	5
PTH #21 N. of Griswold	WQ0008	7/1965-10/1977	62	270	58	5
18th St. bridge Brandon	WQ0009	7/1965-9/1989	215	440	53	5
Above Brandon steam plant	WQ0010	7/1965-12/1977	87	540	36	5
Brandon lagoon	WQ0011	1/1973-12/1977	45	460	72	5
PR #340 at Treesbank Ferry	WQ0012	7/1965-9/1989	132	1400	61	5
PTH #34 N. of Holland	WQ0013	7/1965-2/1984	139	1160	83	5

TABLE 5 Continued

Station Location	Station No.	Sampling Period	No. of Samples	Concentration (mg l^{-1}) Max.	Mean	Min.
TCH E. of Portage la Prairie	WQ0015	7/1965-9/1989	195	1290	94	5
PR #430 S.E. of Poplar Pt.	WQ0016	11/1968-10/1977	63	477	100	5
TCH W. of Headingley	WQ0017	7/1965-5/1986	70	520	129	5
PR #334 S. of Headingley	WQ0018	7/1965-4/1989	184	892	100	5
Main St. bridge Winnipeg	WQ0019	1/1967-5/1986	103	504	85	5
PR #340 nr. Treesbank	WQ0350	7/1965-9/1989	113	840	43	5
PTH #4 W. of Russell	WQ0363	2/1978-3/1984	73	798	39	5
PTH #22 at Souris	WQ0371	3/1978-9/1989	61	121	18	5
PR #240 S. of Portage	WQ0391	9/1981-2/1984	73	1740	142	5
CNR bridge E. of Brandon	WQ0406	5/1973-11/1973	7	85	41	10
Headingley	WQ0451	1/1978-11/1989	284	866	103	3
Main St. bridge Winnipeg	WQ0453	1/1978-11/1989	271	936	94	6
4 miles N. of Elie (PR #248)	WQ0616	6/1983-12/1984	14	260	97	17

much more reliable and useful indication of the range and duration of suspended sediment concentrations, and the relationship between concentration and discharge, than do the water quality data.

Two Federal water quality stations coincide with WRB sediment station locations - at Kamsack and near Russell. In both cases the measured N.F.R. concentrations are within the range of concentrations measured at the WRB sediment stations. Three Provincial water quality stations coincide with WRB sediment stations. WQ0013 near Holland has a maximum sampled concentration below that measured by WRB, but the mean concentrations are fairly close to each other. WQ0363 and 0378 near Russell have mean concentrations similar to the WRB data, but maximum concentrations higher than those recorded by WRB (798 mg l^{-1} versus 437 mg l^{-1}). This discrepancy can be accounted for by the non-overlapping sampling periods. Finally, WQ0451 at Headingley has a sampled maximum concentration lower than that of the WRB data, but a mean concentration very close to that of the WRB data.

11. SUSPENDED SEDIMENT LOAD AND YIELD OF THE ASSINIBOINE RIVER

The preceding sections have summarized the available sediment data for the Assiniboine River. The purposes of this section are to synthesise those analyses in order to identify trends in the sediment regime downstream through the system and suggest the likely sources and sinks of sediment on a basin scale.

11.1 Downstream Trends in Sediment Regime Characteristics

Some of the key sediment regime characteristics of the Assiniboine River presented in the station analyses (sections 4 - 10) are summarized in Table 6. These data were chosen to give a brief impression of the general downstream trends in such aspects of the sediment regime as typical concentrations and loads, and the time distribution of the load. The periods of record are not exactly the same, but these parameters are not very sensitive to these differences provided a reasonably long record exists. The differences in the period of record are certainly not sufficient to change the relative differences between the stations. The data from Rossendale represent only two or three years of record and for that reason are probably misleading indications of the regime at that station and have not been included. Total loads and yields are discussed in subsequent sections (11.2 and 11.3). In addition, an attempt has been made to indicate some of the effects of the Portage Diversion sediment regime. Further details on these data are in the individual station analyses.

TABLE 6 Summary of Sediment Regime Characteristics

Station Name	'Mean Annual conc. (mg l^{-1})	Concentration Duration % of time			Daily Load Duration % of time			'Best %'		Duration of 'Effective' Discharge	% of time to transport 80% of load
		Median	Max.	>300 mg l^{-1}	Median	Max.	>1 000 Mg	1	10		
Assiniboine R. at Kamsack	52	24	338	1	3	2 140	< 1	15	68	6 - 10 %	13
Assinboine R. nr. Russell	48	23	437	< 1	15	1 220	< 1	9	39	5 - 6 %	25
Assiniboine R. nr. Holland	311	63	2 670	8	112	98 800	17	15	53	7 - 12 %	8
Assiniboine R. nr. Portage la Prairie											
1962 - 1969	408	146	3 081	14	142	103 000	22	19	68	8 - 11 %	12
1970 - 1979	231	103	2 251	7	251	51 801	19	11	49	1 - 2 %	15
1962 - 1979	284	121	3 081	10	220	103 000	20	14	57	3 - 5 %	14
Assiniboine R. nr. Headingley											
1962 - 1969	360	134	2 110	15	204	56 900	21	22	68	7 - 9 %	12
1970 - 1987	263	107	1 710	8	117	49 400	20	13	49	2 - 3 %	16
1962 - 1987	286	115	2 500	10	182	56 900	22	16	55	2 - 4 %	14

* {(mean annual load (Mg) / mean annual total discharge (dam^3)} x 1000

Some general trends are readily apparent from Table 6.

1. Average daily, maximum daily and mean annual suspended sediment concentrations increase progressively downstream, as does the duration of concentrations greater than 300 mg l^{-1} - although there is little difference between Portage and Headingley (Fig. 76). Concentrations at Portage and Headingley have been considerably reduced by the Portage Diversion.

2. Average daily and maximum daily suspended sediment loads increase dramatically between Russell and Holland, and then less rapidly between Holland and Portage.

3. There is no marked downstream trend in the proportion of the annual or seasonal load transported by the consecutive days representing 1% and 10% of the year or season (April-October). Note, however, that because of the way these 'best %' data are calculated there may be differences between the upstream and downstream stations that are not initially apparent. For the two upstream stations (Kamsack and Russell), the 1% and 10% time periods represent only 2 and 24 days (1% and 10% of the period April 1 - October 31) respectively, rather than 4 and 37 days. Assuming that the bulk of the annual load is transported during the

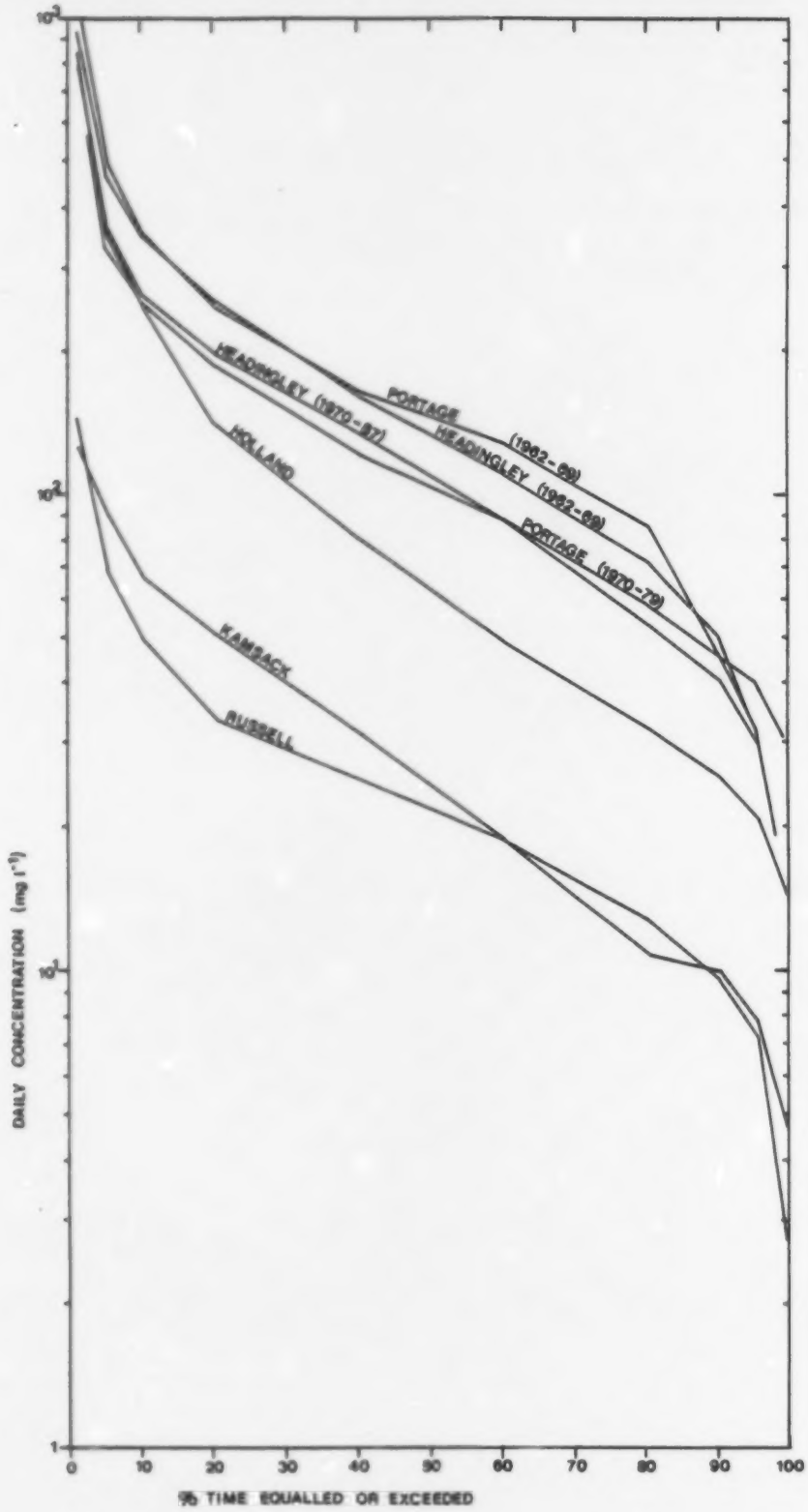


Figure 76 Comparison of Daily Concentration Duration Curves for All Stations

period April-October then the 4 and 37 day loads at these stations would actually represent a much greater proportion of the annual load than appears from the calculation based on the season April-October. The fact that the Russell data are collected a short distance downstream of the Shellmouth Dam accounts for the low values at that station.

4. The opening of the Portage Diversion has reduced the proportion of the annual load transported by the highest consecutive 4 and 37 day loads at Portage and Headingley. This is to be expected given that the Diversion flows and loads are highest during flood events and therefore the peak discharge loads are preferentially diverted out of the Assiniboine River, leaving the lower discharges to transport proportionally more of the remaining total load.

5. The period of time taken to transport 80% of the annual or seasonal load changes little downstream. Again, the percentage figures are misleading because in the case of Kamsack and Russell they represent percentages of the period April-October (244 days), while for Holland, Portage and Headingley they represent the full year (365 days). Thus, there is a downstream trend towards the load being spread over a longer time period (Fig. 77).

Bed material and suspended sediment particle size also show systematic trends downstream along the river from Holland to Headingley (see sections 6-9 for details at each station). D_{50} of the suspended sediment decreases from 0.015 mm to 0.006 mm, and the percentage sand decreases from 26% to 3%, while percentage clay increases from 23% to 39% (Fig. 78).

Rannie (in press) shows that bed material particle size decreases systematically from Holland to Headingley (Fig. 78). The bed material samples suggest that D_{50} decreases from 0.48 mm near Holland, to 0.44 mm at Portage and 0.31 mm at Headingley. Percent gravel (> 2 mm) decreases from 15-20% to 5-10%. Wolowich and Tamburi (1985) report the presence of large cobbles derived from glacial till in some sections of the channel through the Assiniboine Delta, including some sections that are extensively armoured for several kilometres and which contribute to the steepening of this portion of the channel. These trends in particle size are a reflection of the sediment sources along the river (e.g. delta versus lake plain sediments), as well as the normal downstream abrasion and sorting of bed material.

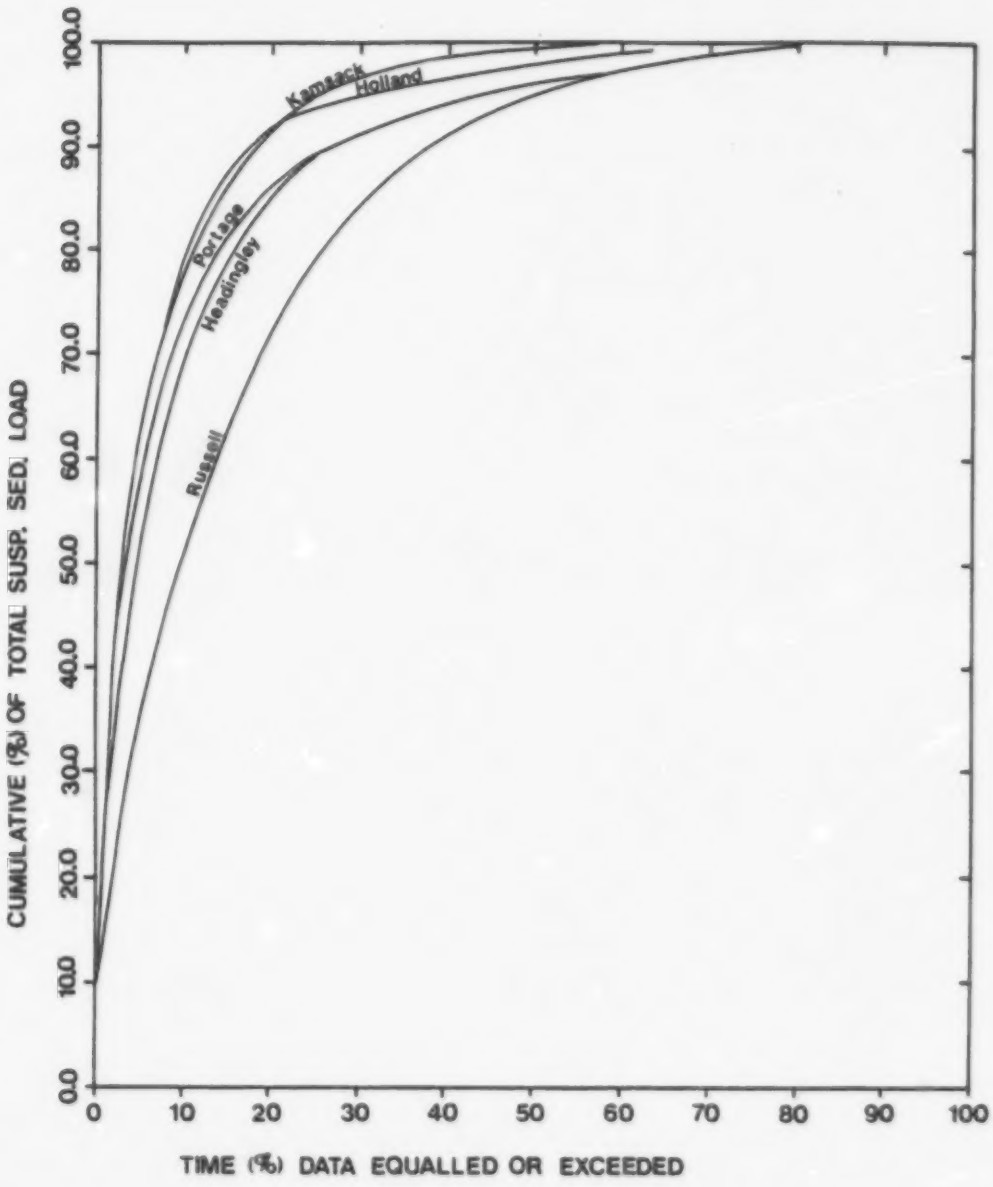


Figure 77 Comparison of Cumulative Load Duration Curves for All Stations

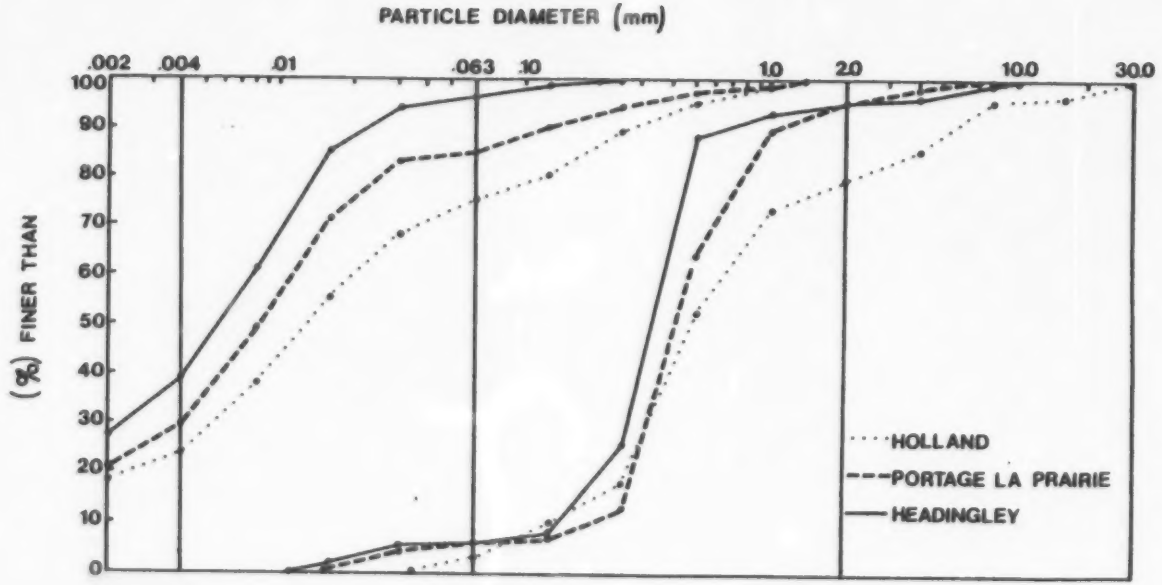


Figure 78 Downstream Trends in Suspended Sediment and Bed Material Particle Size (from Rannie, in press)

11.2 Mean Annual Suspended Sediment Load

The annual and seasonal sediment loads at each of the sixstations on the Assiniboine River, and the two major tributaries (Qu'Appelle River near Welby 05MJ001 and Souris River at Wawanesa 05NG001) are listed in Table 7. Note that the computed load for the Qu'Appelle River near Welby is based on a suspended sediment rating curve and flow duration curve for the period 1975 to 1985. Using the complete record at each station there is a dramatic contrast between the annual loads at the two upstream stations (Kamsack and Russell) where mean annual loads are less than 20 000 Mg, and those downstream (Holland, Rossendale, Portage la Prairie and Headingley) where mean annual loads are over 500 000 Mg. The contributions of the two major tributaries (Qu'Appelle and Souris) to this increase in load are minor. Although the load at Russell is influenced by the Lake of the Prairies it seems unlikely that the 'natural' load at Russell could be greater than 30 000 Mg, given the typical concentrations and specific yields in the upstream portion of the basin. Mean total annual discharge increases about four fold between Russell and Holland, which is proportionally much less than the increase in load.

Downstream of Holland and Rossendale, the calculation of the change in mean annual load in the downstream direction is confounded by the Portage Diversion. There are no data on pre-reservoir loads upstream of the reservoir so that it is impossible to know how the loads changed downstream, under natural conditions,

TABLE 7 Total Annual / Seasonal Suspended Sediment Loads for the Assiniboine River

Year	Kamsack	Russell	Holland	Rossendale	Portage	Headingley	Qu'Appelle*	Souris
1962						283 000		
1963					262 000	257 000		
1964					293 000	319 000		
1965					620 000	596 000		
1966					611 000	532 000		
1967					432 000	413 000		
1968					151 000	161 000		
1969	'5 770				1 180 000	887 000		
1970	'8 890	13 600			497 000	577 000		
1971	'17 700	'6 100	'486 000	707 000	281 000	408 000		
1972	'15 300	'18 500	'699 000	'630 000	282 000	547 000		
1973	'1 740	2 000			59 300	81 200		
1974	'14 800	21 000	'1 300 000		942 000	844 000		
1975	'23 900	19 400	1 340 000		673 000	835 000	103 398	
1976	'26 900	29 000	1 910 000		1 220 000	1 080 000	133 659	
1977	'2 850		44 000		49 000	46 700	7 564	
1978	'4 430		169 000		155 000	232 000	6 898	
1979	'19 900		1 630 000		553 000	1 020 000	50 164	
1980			73 000			106 000	10 745	
1981			33 000			35 600	5 380	2 272
1982			314 000			265 000	29 204	42 742
1983			575 000			465 000	40 985	67 666
1984			50 000			91 500	7 328	4 348
1985			287 000			339 000	26 978	21 657
1986			423 000			416 000	14 966	13 267
1987			'306 000			'244 000	7 303	51 700
Mean	13 000	15 700	659 000	668 000	503 760	520 118	34 198	29 093
S.D.	8 750	9 230	665 000	54 400	357 000	'307 000	40 527	25 241
S.E.(%)	20.3	22.2	25.2	5.8	17.2	11.6	32.8	32.8

' Seasonal load only

Estimated from suspended sediment rating curve

between Holland and Portage. However, there are pre-reservoir data for the two stations downstream of the Portage Diversion. These show that for the years 1963 to 1969 the mean annual loads were lower at Headingley (452 000 Mg) than at Portage (508 000 Mg) suggesting net depostion along the lower reaches of the Assiniboine River. A t-test of the difference in the means showed no significant difference at 95% confidence limit. Therefore there are no statistical grounds for concluding that the reach between Portage and Headingley was one of net deposition under natural conditions. In fact much of the difference in the means is accounted for in the load estimates for 1969 alone.

After construction of the Portage reservoir, the relative loads at Portage and Headingley are the reverse of those from the pre-construction data - mean annual load at Portage for 1970-1979 is 471 000 Mg and for Headingley it is 567 000 Mg. Therefore, instead of a downstream decrease, there is an apparent downstream increase in load of about 20%. However, t-test of the difference between the means again showed no significant difference at 95% confidence limit.

The general conclusion, therefore, is that after the river emerges from the incised section through the Assiniboine Delta, no significant changes in mean annual load occurred under natural conditions. Therefore, the major sediment source region within the basin is that portion between Russell and Portage, and probably, more

precisely, the reach between Brandon and Rossendale where the river is incised into the silty sand of the Assiniboine Delta. Further consideration is given to sediment sources later in this discussion.

The mean annual load data also allow examination of the effects of the Portage Diversion on the load of the Assiniboine River downstream. The period of overlapping data for the river upstream, downstream and in the Diversion covers the years 1971 to 1979, omitting 1973. There are two sediment stations on the Diversion channel itself but the one near the upstream end (Portage Diversion near Portage la Prairie, 05LL019) is used here, to minimize the error in the load estimate that might occur due to erosion of the Diversion channel.

On average, for the period 1971 to 1979, mean annual load measured downstream of the Diversion near Portage is 58% of that near Holland (949 000 Mg near Holland and 456 000 Mg near Portage). This proportion ranges from 34 % in 1979 to 92 % in 1978 (in 1978 Diversion discharges averaged less than 2 $m^3 s^{-1}$ during April, the only month in which flows occurred). In 1977, the only one of these years in which no flow was diverted, the load at Portage exceeded that at Holland by about 10 % (44 700 Mg near Holland and 49 000 Mg near Portage). The mean annual load through the Diversion during this period was 259 000 Mg - 27 % of the load at Holland (Table 8).

Most of the difference between the loads at Holland and Portage that cannot be attributed to the Diversion is presumably the result of deposition in the Portage reservoir. Over the period between 1970 and 1979 this averaged 234 000 Mg. Estimates of the deposition in Portage Reservoir between 1971 and 1977 suggest net deposition of 630 acre-feet (Inland Waters Directorate and Manitoba Department of Natural Resources, 1982). When converted to a dry weight, this is within a few percent of the net deposition calculated from the suspended sediment load input and output from the reservoir during the same period.

During the period from 1970 to 1979 the total flow passing through the upstream end of the Diversion (05LL019) is 4 326 000 dam^3. The total discharge for the same period in the Assiniboine River near Holland and near Portage la Prairie are 25 863 000 and 20 378 000 dam^3 respectively. The total discharge in the Diversion and near Portage does not quite sum to the total near Holland, perhaps due to evapourative losses, but during this period the Diversion flows are 16.7 % of the flow near Holland, and the total discharge at Portage has accordingly been reduced by a similar amount.

Thus, on average, between 1970 and 1979, 14% of the discharge input and 27 % of the sediment input from Holland have been diverted. This unequal partitioning of sediment load and discharge, combined with the deposition in the Portage Reservoir,

TABLE 8 Annual Load and Discharge of the Portage Diversion near Portage la Prairie (05LL019)

Year	Annual Load (Mg)	Annual Discharge (dam^3)
1970	94 200	262 000
1971	8 050	31 400
1972	61 300	30 500
1974	296 000	649 000
1975	231 000	663 000
1976	916 000	1 760 000
1978		4 210
1979	209 000	652 000

is responsible for the reduction in average suspended sediment concentrations downstream at Portage and Headingley (see Sections 8 and 9). The mean annual load / flow ratio for the Diversion is 512 mg l^{-1}, compared with 231 in the Assiniboine River at Portage and 367 mg l^{-1} near Holland from 1970-1979. These figures for mean annual load during the common period 1970 to 1979 are summarized in Figure 79.

11.3 Mean Annual Specific Suspended Sediment Yield

The estimation of the mean annual suspended sediment yields for each station is difficult because of the problem of establishing the area contributing sediment to a particular station. This includes the consideration of the 'dead' drainage area for each sub-basin, as well as the trapping efficiency of the reservoirs in the basin. The following estimates for each of the stations:

1. KAMSACK: There is only one small reservoir upstream of Kamsack (Theodore Dam) which may trap a significant quantity of sediment. Eliminating the drainage area upstream of this reservoir (gross = 2 640 km^2) gives a yield, for 1969-1979, of 1.3 Mg km^{-2} $yr.^{-1}$, for the gross drainage area.

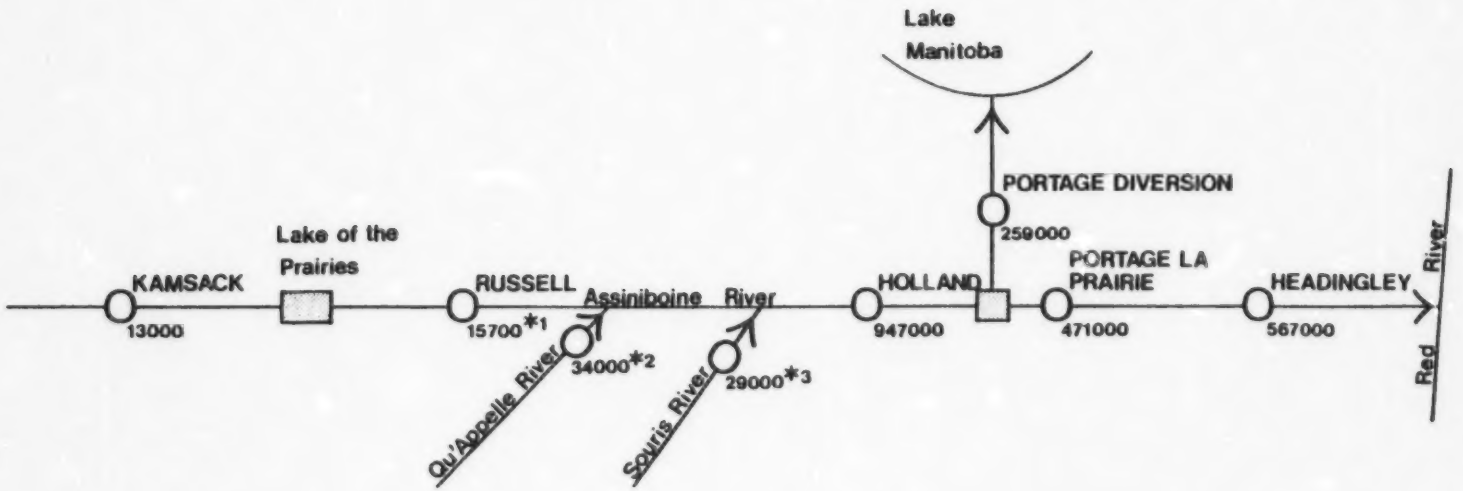


Figure 79 Summary of Mean Annual Suspended Sediment Budget for the Assiniboine River, 1970-1979

2. RUSSELL: The inflow:capacity ratio of Shellmouth Reservoir suggest that it should have a trapping efficiency of over 90%. Therefore, the area delivering sediment to the Assiniboine River near Russell should be only that drainage area downstream of Shellmouth Dam (1 000 km ^{2}). In that case the mean annual suspended sediment yield is approximately 16 Mg km^{2} yr.$^{-1}$. The Provincial water quality station downstream of the spillway recorded concentrations no higher than 30 mg l^{-1} (Table 5), which suggests that much of the suspended sediment is derived from the channel downstream of the dam.

3. HOLLAND: Between Russell and Holland the Assiniboine recieves several significant tributaries, especially the Qu'Appelle, Souris and Little Saskatchewan rivers. The Qu'Appelle River has a series of lakes along its course which are likely to be effective sediment traps. If so, then the area upstream of these lakes (47 100 km^{2}) can be eliminated from consideration. Similarly, the Little Saskatchewan River has a reservoir near its downstream end (at Rivers) which may trap much of its sediment load, potentially eliminating a further
3 910 km^{2}.

The situation on the Souris River is difficult to assess. A series of control structures in the Souris Natioanl Wildlife Refuge immediately south of the Canada/U.S. border might be expected to trap the sediment load from upstream. Yet suspended sediment data from the Souris River near Coulter, immediately north of the border, indicate mean annual loads averaging 5 900 Mg between 1981 and 1987. However, this is only about 20% of the load near the mouth of the Souris at Wawanesa during the same period, which is itself only about 10% of the total load of the Assiniboine River near Holland for that period. Completely eliminating the area upstream of Coulter (47 100 km^2) may underestimate the contributing area of the Souris River but it is clear that the specific yield and the total load of the Souris River are small compared to that of the Assiniboine River.

Taking all these considerations into account, and ignoring the area upstream of the Shellmouth Dam, suggests that the gross contributing area for sediment upstream of Holland could be as low as 40 000 km^2, and the 'effective' area would be between 30 and 40 % of that. In that case, mean annual specific yields at Holland for the period of record would be 16 Mg km^{-2} $yr.^{-1}$ for the gross drainage area and proportionally higher for the 'effective' area. For the years 1971 to 1979 this would be

about 17 Mg km^{-1} $yr.^{-1}$. Inclusion of larger contributing areas for the Souris and Qu'Appelle basins in particular would reduce this figure accordingly.

4. ROSSENDALE: Much the same arguments apply here as to Holland. The gross drainage area is larger than that at Holland by only 200 km^2.

5. PORTAGE LA PRAIRIE AND HEADINGLEY: These stations contain information on loads prior to construction of the Shellmouth Dam and the Portage Reservoir. In that case much of the drainage basin upstream of these two stations potentially contributed sediment, except that the assumptions made about the contributing area of the Qu'Appelle and Souris basins, made in connection with the specific yield at Holland, apply here. Given these assumptions, the gross drainage areas contributing sediment to the two stations are 62 400 and 63 400 km^2 for Portage and Headingley respectively. Again, the 'effective' areas are 30 -40 % of the gross. For the gross drainage areas, this suggests mean annual yields of 7 - 8 Mg km^{-2} yr^{-1}, for the period 1962 - 1969. Since 1969, the specific yield for these stations means very little given the trapping efficiency of the Portage Reservoir and the quantity of sediment passing down the Diversion.

While the calculation of the estimates of sediment yield are subject to errors due to both load estimation and contributing area estimation, the overall trend can be identified fairly easily. The yields are low (probably 1 - 3 Mg km^{-2} yr^{-1}) in the headwaters of the Assiniboine River and in the major tributaries (Qu'Appelle and Souris rivers), increase substantially in the central portion of the basin through the Assiniboine Delta, and decline again downstream. The sediment load data suggest that very little load is added to the river where it crosses the Lake Agassiz plain, and the yield from this portion of the basin may be practically zero, apart from drainage ditch erosion.

11.4 Sediment Sources

The review of the annual load and yield data make it clear that the bulk of the load of the Assiniboine River is derived from the central portion of the basin between Russell and Portage la Prairie. Whether this load is derived predominantly from the basin upstream or downstream of Brandon is difficult to be sure of in the absence of sediment data at Brandon. However, it seems unlikely that the basin upstream of Brandon would be a major source for sediment in the river.

The character of the valley changes very little between Russell and Brandon, although the average discharge doubles. The river remains confined within the

Assiniboine spillway and retains its sinuous meandering course, which occasionally abuts the valley side. Much (about 50%) of the increased discharge is supplied by the Qu'Appelle River and the bulk of the remainder by three or four tributaries, of which the Little Saskatchewan River has the largest discharge. The valley side of the Assiniboine River is dissected locally by gullies and ravines occupied by ephemeral streams which rise on the plains a few kilometres away from the valley. The Qu'Appelle River has an estimated mean annual load of 34 000 Mg, which is only about 5% of the load of the Assiniboine River near Holland. The other major tributary downstream of Russell is the Little Saskatchewan River. The Rivers Reservoir potentially traps much of the load of the Little Saskatchewan River, and this, combined with the fact that the other tributaries all have mean annual flows of 20 000 dam^3 or less, suggests that sediment supply from the tributaries is likely to be quite small. These tributaries are for the most part low gradient tortuous streams confined in spillways or narrow valleys in much the same fashion as the Assiniboine itself.

The upland areas in this portion of the basin are dominated by low relief hummocky moraine topography with extensive areas of internally drained sloughs. The drainage network is poorly integrated, except close to the larger streams, which may well preclude much field erosion from reaching the stream system. For the most part soil erosion risk is low to negligible in these areas (Eilers et al., 1987), except locally where steeper slopes on valley sides occur. The area north of the Assiniboine River

and south of a line between Birtle and Rivers is mapped as having severe soil erosion risk (Eilers et al., 1987) but once more the poorly-integrated drainage may preclude this from translating into a significant source of fluvial sediment. This low risk is present regardless of land use, or proportion of the area under cultivation, suggesting that land use changes may have little impact on the sediment load of the Assiniboine River.

Similar arguments apply to the sediment supply from tributaries and upland erosion downstream of Brandon. The Souris River, the major tributary along this section, adds a mean annual load of 29 000 Mg (1981-1987), about 5% of that measured near Holland (659 000 Mg, 1971-1987). The Souris River seems to derive much of its load from the downstream portion of its course where it steepens and incises prior to joining the Assiniboine. The mean annual load of the Souris near its downstream end (at Wawanesa, 05NG001) is about five times that upstream at the Canada\U.S. border near Coulter (05NF016).

This increase in sediment supply is also apparent in the morphology of the river which, near the Assiniboine confluence, meanders in an incised valley with large river bluffs and contains extensive unvegetated in-channel deposits suggestive of a large local sediment supply. This steeper reach is developed as a result of the historical (and perhaps current) incision of the Assiniboine River through the Assiniboine Delta.

Lowering of the local base level of the Souris has resulted in incision and steepening of the lower course of the river. This provides local steep valley sides cut into Quaternary sediments and Cretaceous shale which may supply sediment to the channel at relatively high rates, thus helping to maintain the steeper gradient along this section. The high yields from this portion of the basin are therfore a product of the geomorphic (post-glacial) history of the drainage basin. Other tributaries along this section such as Cypress River are minor and unlikely to contribute significant quantities of sediment.

Aerial photographs of the Assiniboine River show that its morphology changes quite abruptly downstream of Brandon. From being an apparently stable river confined within the Assiniboine spillway, it rapidly incises into the silty sand of the Assiniboine Delta. The river shows obvious signs of lateral instability - extensive point bars and cutoff channels - and active transport of sediment, as seen in the numerous lateral and mid-channel sand bars, which are often unvegetated. The long profile shows that the river steepens considerably along this reach, beginning immediately downstream of Brandon (see section 2). This is the result of post-glacial incision into the Assiniboine Delta and is presumably maintained by the increased supply of coarser sediment.

Wolowich and Tamburi (1975) report active slumping along portions of this valley, which they suggest may supply significant quantities of sediment, as well as erosion of the river bluffs. Riparian erosion of the deltaic sands is apparently also

greatly assisted by spring sapping in numerous locations (Wolowich and Tamburi, 1985). The particle size distribution of the bed material at Holland and downstream may well reflect these sediment sources. Rannie (in press) and Everitt (pers. comm. 1990), also suggest that much of the sediment load of the river is derived from riparian erosion in the section between Brandon and Portage.

12 CONCLUSIONS

The following conclusions are drawn from consideration of the station analyses and discussion of the sediment load and yield of the Assiniboine River.

1. The coverage of the range of flows by suspended sediment sampling is at least satisfactory in all cases, except near Rossendale where the record is too short to have adequately covered the flow range. Specifically:

   Kamsack - covers the complete flow range since 1944 and includes the 5 highest annual maximum and annual total discharges.

   Russell - similar to Kamsack but only covers the range of flows since construction of the Shellmouth Dam.

   Holland - the flow record is only a few years longer than the sediment record but the full range of flows is covered, including the period 1974-1976 which recorded the highest discharges of the recent past in the Assiniboine River.

   Portage la Prairie - covers several years of pre and post-Diversion flows and includes the highest annual maximum discharge and second highest annual total discharge.

   Headingley - has covered the full range of flows since 1956 and compares favourably with the complete flow record since 1913.

Therefore, continued sampling at the currently active stations could do little to improve the present flow coverage.

2. All the sediment and discharge regimes are affected to a greater or lesser extent by flow regulation.

Kamsack - affected by only minor flow regulation schemes in the upper portion of the basin.

Russell - the operation of the Shellmouth Dam (Lake of the Prairies) has reduced April flows substantially and removed the late April peak, which is delayed until mid May. Sediment concentration continues to peak in late April and therefore does not coincide with the flow peak.

Holland - this station is sufficiently far downstream of the Lake of the Prairies that its regime is affected much less than that at Russell. There is little change in the timing of peak flows and sediment concentrations but spring peak discharges are reduced by about 25%. There is no information on the pre-reservoir concentration regime.

Portage la Prairie - the effect of flow regulation varies with the operation of the Diversion. In low flow years there is no alteration of the regime. In high flow years total discharges may be reduced by 15 - 20 % and the April flood peak is removed. Summer, fall and winter flows are augmented. On average the peak discharge occurs two weeks later than

it would naturally. Peak concentrations have been reduced by up to 50% and do not necessarily coincide with the peak discharge event. The annual load has been redistributed so that proportionally less is transported in April than under natural conditions.

Headingley - the effect here is almost identical to that at Portage, although the reductions in concentration are not quite as great.

3. All the sediment regimes show clockwise hysteresis in the relationship between suspended sediment concentration and discharge. This pattern is dominated by the effect of higher concentrations on the rising limb than the falling limb of the spring flood hydrograph. In some cases this is confused by flow regulation which delays the discharge peak without influencing the timing of the sediment concentration peak.

4. Daily concentrations increase downstream across the whole flow range. The increase between Russell and Holland is particularly obvious, but there is also an increase between Holland and Portage.

5. Bed material particle size is generally coarse-medium sand (D_{50} typically 0.4 - 0.5 mm) with 5 - 10% gravel in the section from Holland to Headingley. At Headingley bed material is slightly finer (D_{50} of 0.3 mm).

6. Depth-integrating samples show D_{50} of the suspended sediment load to be in the range 0.002 - 0.3 mm. In all four of the downstream stations (Holland, Rossendale, Portage and Headingley) D_{50} and percentage sand of the suspended load increased markedly at high discharges, indicating entrainment of bed material at high stage. The high sand concentrations close to the bed in many of the point-integrating samples confirms this.

7. The mean annual load increases rapidly (about 20 times) between Russell and Holland and then changes very little along the rest of the river. The absence of pre Portage Diversion data upstream of Portage preclude any statements about the increase in load downstream of Holland prior to the opening of the Diversion. However, the load changes very little downstream of Portage both before and after the opening of the Diversion.

8. The Portage Reservoir and Diversion intercept about 40% of the load of the Assiniboine River. This proportion varies with the quantity of water diverted and therefore differs for each year of record. Of this, about 25% (259 000 Mg on average) passes down the Diversion and the remaining 15% is trapped in the reservoir.

9. The standard error of the estimates of mean annual load are fairly high in all cases (usually 20 - 30%). There is little liklihood of increasing this precision without substantially longer sediment records which may not be worth the extra cost.

10. Calculation of the mean annual specific yield is difficult because of uncertainty about the extent of the contributing area and particularly the trapping efficiency of the major reservoirs on both the main stem and the tributaries. Based on gross drainage areas the yield appears to be extremely low (less than 3 Mg km^{-2} yr^{-1}) in the upper Assiniboine (upstream of Kamsack) and in the major tributaries (Qu'Appelle and Souris). Further downstream, in the central portion of the basin between Brandon and Portage, yields increase to about 16 Mg km^{-1} yr^{-1}. Downstream of Portage yields were in the range 7 - 8 Mg km^{-1} yr^{-1} prior to the opening of the Portage Diversion, but with the Portage reservoir and the Diversion acting as major sinks calculation of yields for this portion of the basin is meaningless. Overall these values for specific sediment yield are all quite low, even compared with other prairie drainage basins (Ashmore and Day, 1988).

11. The rapid increase in load, yield and average concentrations between Russell and Holland, and the absence of major increases further downstream, suggest that the central portion of the basin is the major area of fluvial sediment supply. The Qu'Appelle and Souris river basins each contribute 5 - 10 % of the load at Holland. The remaining tributaries appear to have the potential to contribute very little (based on their discharges and the soil erosion risk maps), and therefore the major source of sediment is likely to be riparian erosion between Brandon and Portage where the river cuts through the Assiniboine Delta deposits. If so, then land use changes and increased soil erosion could have limited impact on the sediment load and quality in the Assiniboine River main stem.

12. In general, the existing WRB sediment data provide a complete description of the post flood control sediment regime of the Assiniboine River. Some potential changes to the network to add futher information are given in the recommendations. The currently active stations at Headingley and Holland have more than adequate data to establish the present sediment regime but may have utility for long-term montoring and continuity of sediment record.

13. Data bases such as soil erosion risk maps, surficial geology and topography provide useful information for interpretation of sediment loads in the Assiniboine basin. Providing such information in a readily accessible computer data base would aid future investigations of this kind.

13 RECOMMENDATIONS

It is recommended that:

1. the potential contribution of sediment from tributaries such as the Little Saskatchewan River be assessed using miscellaneous sampling programs.

2. a sediment station be established on the Assiniboine River at Brandon to confirm that the section downstream of Brandon is the primary sediment source for the Assiniboine River.

4. the operation of the sediment station at Holland be continued while the loads at Brandon are established.

5. the sediment station at Headingley be discontinued unless data needs other than those addressed by the WRB program are identified, or a need is seen for continuity in the sediment record for the whole basin.

6. the possibility that high sediment loads downstream of the Lake of the Prairies are derived from channel degradation and bank erosion be assessed.

7. a complete survey of the potential sediment contributing areas based on existing runoff contributing area maps be carried out, and the extent to which upland soil erosion might be a source for fluvial sediment be more thoroughly assessed.

8. that a geographic information system-based data base be established to provide easily accessible information on land use, topography, surficial geology, erosion risk, climate, hydrology, water quality, and monitoring networks to facilitate future integrated environmental studies in this basin and others.

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